Status of the ALPS Experiment

Since the last report to the PRC in November 2007 the ALPS experiment has been improved considerably. Data taking was concluded successfully in the so-called phase 1. ALPS has now reached a sensitivity which is only surpassed by the GammeV experiment at FERMILAB (Phys. Rev. Lett. 100, 080402, 2008) despite the fact that some milestones could not be reached due to various reasons.
In the subsequent sections an update of the physics case is presented followed by sketches of the status of the experiment, of the physics results and the next steps.

Update of the Physics Case

Theory and Phenomenology

Shedding light on the hidden sector of string theory:
Extensions of the standard model which are based on supersymmetry, supergravity, or string theory predict the existence of a hidden sector of new particles and interactions. The hidden sector particles have only very weak interactions with the visible sector, standard model particles, arising from the exchange of very massive messenger particles. For simplicity and in order to avoid low energy constraints, it has been assumed in the literature that all the particles in the hidden sector are very heavy. However, recently it has been pointed out that in the context of realistic string compactifications some of the hidden sector particles may indeed be very light, with masses in the sub-eV range (http://arxiv.org/pdf/hep-ph/0608248 and http://arxiv.org/pdf/0803.1449v1). This often reflects symmetries of the particular compactification or more generally of the particular high energy completion of the theory. Of particular interest in this connection are here hidden sector U(1) bosons and hidden sector fermions charged under these U(1)s. Moreover, it has been found (http://link.aps.org/abstract/PRD/V76/P115005) that laser experiments open up a unique window. They have a large discovery potential for light hidden sector particles which exceeds the potential of experiments at high energy accelerators and can be even superior to the sensitivity of astrophysical and cosmological probes. In fact, the best limit on meV-mass hidden photons kinetically mixing with the visible photon can be obtained currently from light-shining-through-walls experiments (http://arxiv.org/pdf/0711.4991) and, in the future, from experiments exploiting high-quality cavities (http://dx.doi.org/10.1016/j.physletb.2007.11.071). A search for solar hidden photons at CAST (http://arxiv.org/pdf/0801.1527) or at SuperKamiokande (http://arxiv.org/pdf/0802.1315) can give interesting information on hidden photons at similar or somewhat larger masses.

Exploring chameleon models of dark energy:
A plausible explanation for the apparent acceleration of the cosmic expansion rate of the universe is provided by the presence of a spatially homogeneous scalar field which is rolling down a very flat potential. The non-observation of “fifth force” effects implies that the forces mediated by these very light particles should be either much weaker than gravity or short-ranged in the laboratory. The latter occurs in theories where the mass of the scalar field depends effectively on the local density of matter – in so called chameleon field theories (http://link.aps.org/abstract/PRL/V93/E171104). Recently, it has been shown that these theories might reveal themselves as an afterglow effect in laser experiments such as ALPS, due to photon-chameleon conversion in a magnetic field

(http://link.aps.org/abstract/PRD/V77/E015018, http://link.aps.org/abstract/PRD/V77/E025016). It was found that afterglow experiments constrain the corresponding parameter space in a way complementary to gravitational and Casimir force experiments.

Other Experiments

The first results of the following on-going light-shining-through-wall experiments have appeared in journals:

- BMV: http://link.aps.org/abstract/PRL/V99/E190403.
- GammeV: http://link.aps.org/abstract/PRL/V100/E080402.
- OSQAR has also published their first results in the form of a preprint, http://arxiv.org/pdf/0712.3362.

There are also news from laser polarization experiments which search for indirect effect of new light particles:

- BMV has written a detailed report on their experimental setup (http://arxiv.org/pdf/0710.1703).
- The first results from Q&A have appeared in (http://dx.doi.org/10.1142/S0217732307025844).

Theory Brainstorming and Calculationshop at DESY

It is envisaged to gather 10-15 selected theorists from outside DESY, collecting ideas about what kind of fundamental questions can be attacked by experiments at the low energy frontier. The goal will be to join forces and write a `White Paper' in support of current and future experiments as well as continuing and strengthening of theoretical efforts.

Status of the Experiment and Next Steps

A first phase of data taking to search for very light axion-like particles and hidden-sector photons was finished in early March. The main difference compared to our previous planning refers to the laser (see below). First steps towards the implementation of phase shifting plates to search for new particles in the meV mass region have started.

Laser System

The main challenge for the laser system at ALPS is to transport a high intensity beam over a distance of about 14 m through an aperture of 18 mm. This demands a beam quality of M^2 close to 1. Therefore systems like the one used by GammeV are not suited for ALPS. After phase 0 with a 3.5 W VERDI-System (as presented at the last PRC meeting in November 2007) the Laser Zentrum Hannover planned to provide an adopted high intensity laser based on a system developed for medical applications. After severe delays in the delivery of such a system (on loan!) from the US, which were beyond our control, the R&D necessary to adopt the laser to ALPS encountered major difficulties. These caused further delay due to the need to purchase components from the US. More important, it became also clear that the system may hardly reach powers well above 20 W. The main reason for this is the necessary change of the beam profile from a “hat-like” structure to a “Gaussian” shape. The peaked Gaussian profile results in too high power densities on the optical components of the laser system, although the overall power is much reduced compared to the 200 W operation of the laser for medical purposes. Therefore we decided to stop the adaptation of a foreign laser but concentrate on systems well known by the collaboration partners.

A laser based on systems developed for gravitational wave detectors like VIRGO or LIGO was set-up at DESY. An infrared laser is amplified by a four-stage system which preserves the beam quality of the primary beam. The 42 W infrared laser beam is frequency doubled in a dedicated crystal resulting in a 532 nm power of 14 W with excellent beam quality matching the ALPS constraints. ALPS took successfully data with this system (Figure 1), which runs very stable.

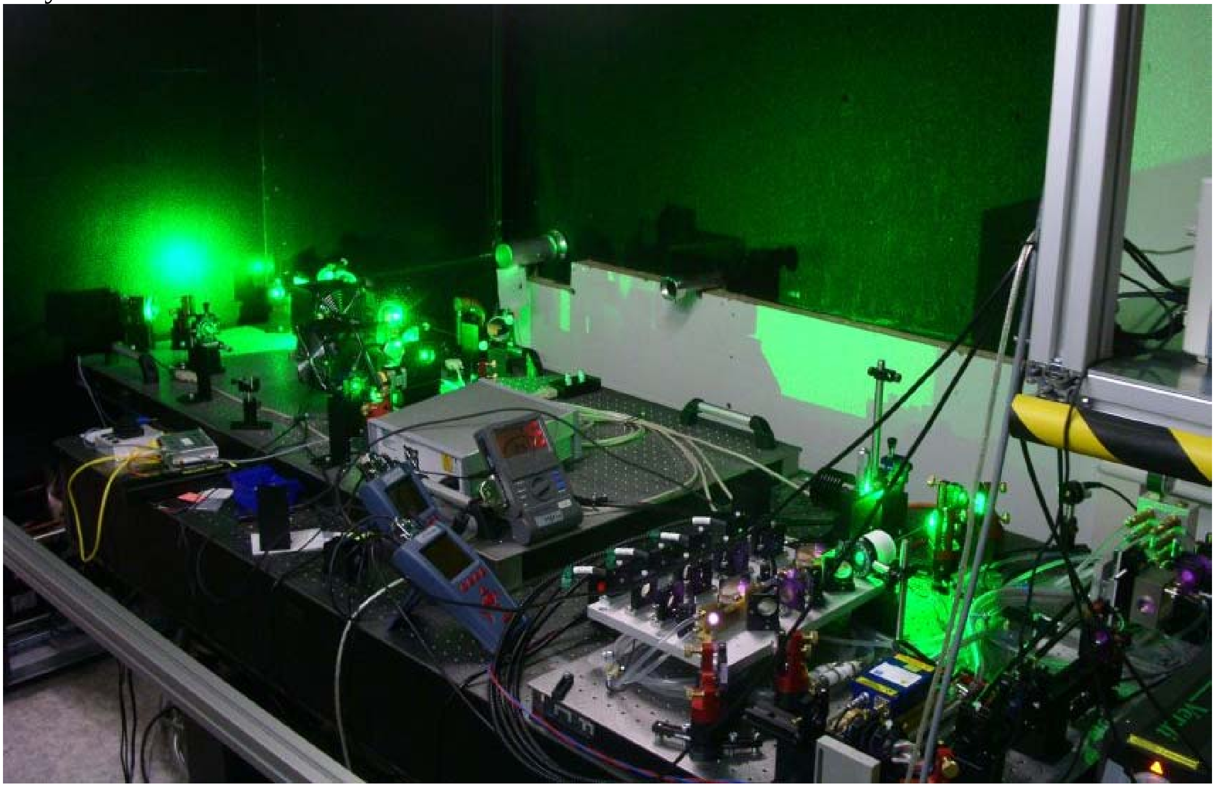


Figure 1: The ALPS laser system with the four stage amplifier on the right below the centre of the image. The 532 nm beam is fed into the magnet via the left illuminated tube. The right tube guides the reference beam.

Clearly the beam power does not match our planning.
However, together with the piezo-controlled mirror in the middle of the ALPS magnet (see below) it serves also as a basis for the next step to increase the effective photon intensity in the magnetic field. Members of a new ALPS collaboration partner, the Max-Planck-Institute for Gravitational Physics (Albert Einstein Institute) in Hannover, have taken responsibility to set-up an optical cavity in the ALPS magnet. Compared to the present configuration this will lead to two orders of magnitude larger laser power in the magnet. Details are described in the document attached.

Magnet

Last autumn the HERA dipole magnet in use for ALPS showed internal hardware problems resulting in frequent quenches for currents above 5,800 A. To avoid further damages it was decided to operate the magnet only at this current thereby limiting the magnetic field strength to 5.16 instead of 5.4 T. In this mode the magnet runs very stable, no further problems occurred. It is not foreseen to exchange the magnet or to modify anything in the set-up.

Magnet Insertions

As announced at the last PRC meeting a piezo-controlled mirror was attached to the laser beam tube and very successfully operated in the middle of the magnet in fields above 5 T. The purpose of the mirror is to reflect the laser light and steer it into a beam dump in the laser hut.

This is a pre-requisite for using lasers with powers well above 3 W, while for the ALPS phase 0 diffuse reflection of the laser light at the end flange of the laser beam tube could be tolerated.

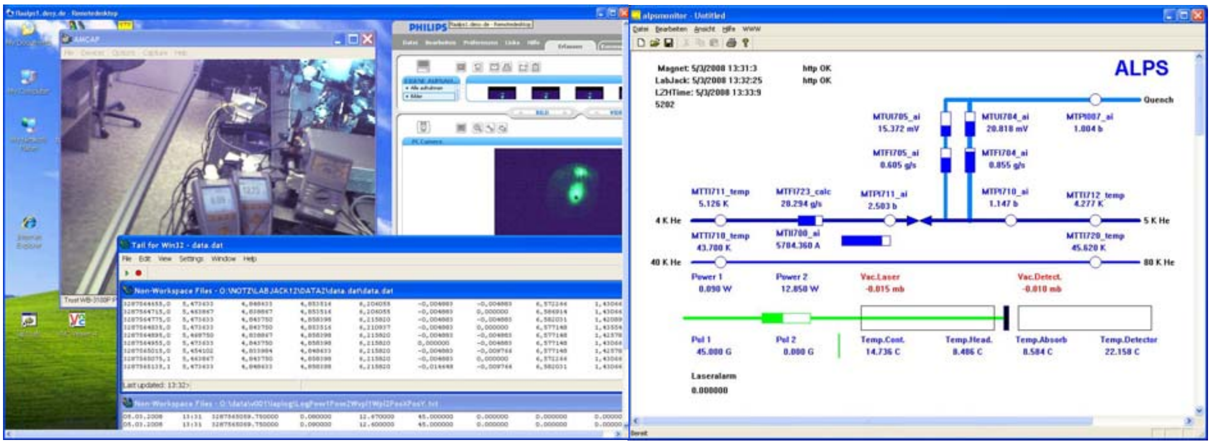
Currently the beam tube at the detector side is either closed by a flange (for data taking) or left open (for alignment purposes). Thus it is not possible to check the alignment of laser beam and detector during data taking, but the beam tube has to be removed, the flange detached and the beam tube inserted back again. Thus ideas are discussed to improve the situation. A first draft layout turned out to be over-constrained and therefore too ambitious to be realized.

Preparations of phase shifting plates to enhance the sensitivity of ALPS for axion-like particles with masses above approximately 1 meV have continued. Prototypes for mounts inside the magnet insertion tubes are being tested. Companies have refused to guarantee the required specifications concerning the parallelism of front and back of the plate. Therefore we have to measure and select appropriate plates ourselves. This will be done by analyzing plates with a Mach-Zehnder interferometer. A first set-up of such an interferometer was doing well. Further work will be continued in a quiet laboratory of the Hamburg University (on the DESY campus) which will be available after middle of May this year.

Detector

Data taking was continued with the modest SBIG 402 STE camera. Due to the problems with R&D of the pulsed laser we did not start the purchase of a new trigger-able CCD. This decision turned out to be correct, because (see above) it was now decided to pursue with an optical cavity instead of a high-power, single pass pulsed laser. The optical cavity will be fed by a cw laser so that triggering is not an issue any more. Hence we are now concentrating on selecting an appropriate low dark current, low read-out noise CCD profiting from recent studies at the Sternwarte Bergedorf on optimal detectors for low-flux spectroscopy. No decision has been taken yet.

Data Acquisition



Magnet: 5/3/2008 13:31:3 http OK
LabJack: 5/3/2008 13:32:25 http OK
LZHTime: 5/3/2008 13:33:9
5202

Figure 2: Examples for online monitoring of laser and magnet via webcams and slow controls.

After increasing the stability of the laser system and implementing slow controls for temperatures at various locations, laser and magnet parameters it is possible since February to run the experiment without any shift person next to ALPS. The responsible shift person checks the experiment at his/her monitor allowing to follow other tasks in parallel (Figure 2). This considerably eases data taking, especially in view of the tight resources of personnel.

Experiences from First Runs and Data Analysis

Data taking started again in January 2008 after installation of the abovementioned laser system. About 110 hours of data with “laser on” were collected in three runs plus many more background data. Here a “run” is defined as data taking between two alignment checks. Please keep in mind, that an alignment check always demands removal of the detector set-up and detector beam tube and re-installation of both components. The main findings of the runs in phase 1 are:

- The set-up of the optical components on the detector breadboard turned out to be not stable enough to guarantee that the laser beam focus hits the same pixel on the CCD during the alignment checks before and after data taking (although this set-up worked perfectly during phase 0 in September 2007):
    - The alignment check after the first run failed completely. In this run also a major fault of the laser system occurred which complicated the alignment test.
    - In the second run the alignment check turned out to be as expected.
    - In the third run it could only be verified that a signal must be contained in a region of $17 \cdot 3$ pixels.

  An improved set-up of the optical components with more stable posts has been realized.
- Data taking was limited by damages on the window closing the laser beam tube in the middle of the HERA dipole. These damages were unexpectedly caused by the high intensity laser beam of 14 W passing this window back and forth. After the damage occurred it was found out that erroneously the company in charge delivered an incorrectly coated window. With a correctly coated window no damages are expected (like the window at the entrance of the laser beam tube for example). A new window is at hand already.
- In the current set-up the pointing accuracy between the fraction of about 10^{-4} of the laser beam intensity which passes through the central mirror in the HERA dipole and photons reconverted from hypothetical new light particles amounts to approximately one pixel on the CCD (9.7 μm). This limits the size of the signal region to $3 \cdot 3$ pixels and is caused by the non-planarity of the back and front surfaces of the mirror in the order of 0.01 degrees. In future the search region will be further reduced by using a collecting lens with shorter focal length in front of the detector.
- The analysis of the CCD data is well under control. The sensitivity is mainly limited by the read-out noise which amounts to 16 e^- per pixel. The dark current is about 0.03 e^- per pixel and second resulting in a poissonian “noise” of 10 e^- per pixel for the longest possible exposure of 3,600 seconds.

The data analysis leads to the following main results:

- A flux of re-converted photons due to the existence of new light particles larger than roughly 50 mHz can be excluded (95% CL). This corresponds to $2 \cdot 10^{-20}$ W.
    - Taking into account the primary photon flux a re-conversion probability of photons to new light particles and back to photons larger than $1.4 \cdot 10^{-21}$ can be excluded.
    - A coupling of axion-like particles to photons larger than $6 \cdot 10^{-7}$ GeV^{-1} can be excluded.
- If the alignment had worked as expected for all runs fluxes of re-converted photons larger than roughly 20 mHz would have been excluded.

The preliminary results of this experiment in comparison to other published results and an outlook for ALPS are displayed in Figure 3 for the search for new axion-like scalar and pseudoscalar particles.

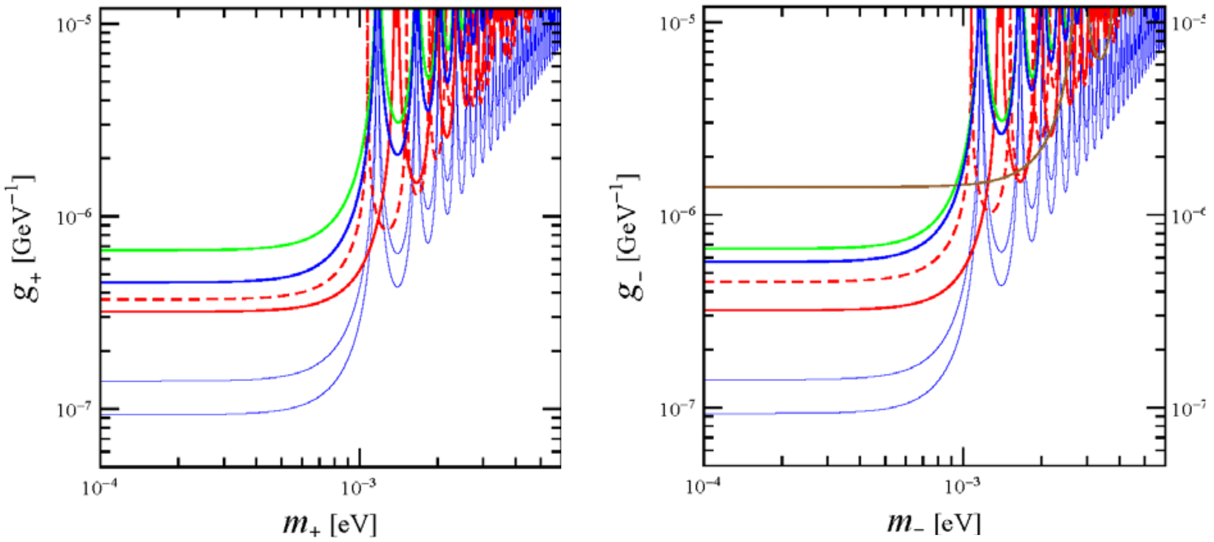


Figure 3: 95% CL limits (BMV, BFRT, ALPS) on the coupling of scalar (left) and pseudoscalar (right) axion-like particles as a function of their mass. Values above the curves are excluded. From top to bottom the results are from BMV (http://link.aps.org/abstract/PRL/V99/E190403*, brown line, only right), BFRT (*http://prola.aps.org/pdf/PRD/v47/i9/p3707_1*, green lines), ALPS (this analysis, thick blue lines) and GammeV (99.7%CL limits) in its two configurations (*http://link.aps.org/abstract/PRL/V100/E080402*, red lines).*
The prospects of ALPS with the optical cavity and with an improved detector in addition are shown as thin blue lines.

As sketched above the ALPS data can also be used to search for massive hidden-sector photons. Preliminary results are shown in Figure 4.

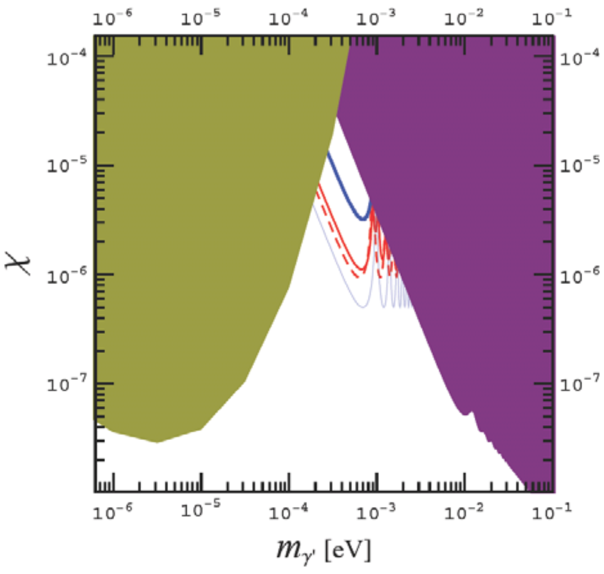


Figure 4: 95% CL limits on the mixing parameter for massive hidden-sector photons as a function of their mass (for details see http://arxiv.org/pdf/0711.4991*). The blue line indicates the preliminary ALPS result; the two red lines show the interpretation of the GammeV data and the thin blue line illustrates the future potential of ALPS. Light-shining-through-a-wall experiments are complementary to searches for deviations of the Coulomb law (green shaded area) and for photon regeneration of hidden-sector photons produced in the Sun within the CAST experiment (violet shaded area, indirect limits from astrophysics are worse).*

More details on the data analysis will be reported at the PRC meeting.

Summary and Outlook

At present ALPS has reached the second best sensitivity of “light-shining-through-a-wall” experiments. Clearly this does not correspond to our time schedule as presented at the last PRC meeting. The delay in achieving “world-best” sensitivities is mainly attributed to the difficulties in the laser development and consecutive uncertainties concerning the requirements of an improved detector.

However, with an optical cavity provided by the new collaboration partner (Max-Planck-Institute for Gravitational Physics (Albert Einstein Institute) in Hannover) an effective increase in laser power by two orders of magnitude is to be expected. Together with a factor of 5 from an improved detector ALPS should be able to exclude re-conversion probability of photons to new light particles and back to photons larger than about 10^{-24} thereby entering new territory. We foresee to reach this sensitivity, which will surpass that of all other published results considerably, in early summer 2008.

Similar to the preliminary results shown above this sensitivity will be used to probe the existence of new axion-light particles and also – from a theoretical point of view even more interesting – massive hidden-sector photons (see Figures 3 and 4). The required beam time with “laser on” is in the order of 100 h like the data taking up to now. To invest much more time is unreasonable because a limit on the coupling of axion-like particles would improve only with the fourth root of the beam time (for an ideal detector). Therefore the results will be available rather soon after finalization of the set-up.

After this exploration the implementation of phase shift plates (see last PRC meeting) in the laser and detector beam tubes will allow to extend the sensitivity to higher masses (beyond 1 meV for axion-like particles). We hope to realize this in autumn 2008.

In parallel we are setting up a dedicated configuration to search for the afterglow of chameleons (see above). The exact configuration will be determined as soon as further theoretical calculations and simulations are finished latest end of April.

Hence we envisage that the potential of the present ALPS-experiment will have been exploited by early 2009. We are ready to present to the PRC first ideas on follow-up experiments to search for weakly interacting sub-eV particles (WISPS) as well as corresponding theoretical motivations and steps towards decisions on such activities.

Fabry Perot cavity assisted power buildup for the ALPS experiment
-conceptual design and implementation plan-

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Introduction

According to theory the axion-like particle generation rate in the ALPS experiment depends linearly on the number of photons in the laser beam travelling through the strong magnetic field of the superconducting HERA dipole magnet. In a first phase of the ALPS experiment a pulsed laser beam with an average power of 13W was used. During this first phase the experimental concept could be demonstrated and the data analysis allowed determining the sensitivity of the current set-up.

Several options could increase this sensitivity, one of which is the enhancement of the laser power in the strong magnetic field.

Given the current laser technology and the required beam quality the most promising way to increase the laser power is to use the power-buildup effect in resonant Fabry Perot cavities. In this document we describe a possible implementation of such a resonant cavity in the ALPS experiment and address the fundamental limitations. Furthermore we will describe a two stage approach to arrive at a two orders of magnitude larger laser power in the HERA magnet which will increase the sensitivity of the ALPS experiment into a scientifically unexplored region.

Experimental technique

The circulating light field in resonant Fabry Perot cavities shows a power buildup factor of $P=F/\pi$ where F is the Finesse of the cavity and this buildup factor describes the ratio of circulating to the injected light power. This equation assumes a loss-less, impedance matched cavity. This effect is used in many optics experiments for several purposes: in laser resonators to increase the stimulated emission rate of the laser transmission, in second harmonic generation experiments were the conversion rate depends on the square of the light power and in gravitational wave detectors (GWDs) to increase their shot noise limited sensitivity to phase changes caused by gravitation waves. Currently GWDs such as the GEO600 detector (Willke et al, Classical and Quantum Gravity, 19, p 1377-87, (2002)) operate Fabry Perot cavities with up to several km length and buildup factors exceeding 1000. For example the light power in the 8m long GEO600 modecleaner cavities which is most relevant for the ALPS experiment is approximately 10kW. The limitation of the maximal achievable build up factor is set by the losses (absorption and scattering) in the dielectric mirror coatings and thermal effects caused by the absorbed light power in the optics which can cause a mismatch between the cavity Eigenmode and the laser mode.

To achieve a high buildup factor feed-back control has to be used to keep the light resonant in the Fabry Perot cavity and to optimize the matching of the laser mode to the Eigenmode of the cavity. The Pound Drever Hall (Black E, Am.J.Phys. 69 (1), 79-87, (2001)) technique is often used to generate an error signal for the deviation of the laser frequency from the resonance frequency of the cavity. Feedback of this signal to either the length of the cavity or the laser frequency can be used to keep the laser resonant in the cavity. Similarly a phase sensitive wavefront measurement technique called differential wavefront sensing (Morrison E et al., Appl. Opt. 33 5041, (1994)) can be applied to generate an error signal for the mode mismatch which can then be used to drive alignment actuators such as piezo mirrors to keep the alignment mismatch to a minimum.

As both techniques provide useful error signals only if the cavity is close to its resonance so called lock acquisition techniques have to be used to bring the system close to is operation point.

All the techniques described above are continuously used and improved by the AEI Group which has as well experience in the reliable operation of long cavities for long durations.

The requirements for the laser system in cavity assisted experiments are much more demanding than for single path experiments. Continuous wave, single mode, single frequency lasers with a well defined polarization state are required. The lasers developed for GWDs have to fulfill similar requirements and the AEI / LZH group is currently developing a 200W laser system for the Advanced LIGO GWD. The so called front-end used in this laser is a master-laser power-amplifier (MOPA) which uses a commercial Innolight 2W Mephisto laser as the seed and four Nd:Vanadat amplifier stages to produce 35W of output power. The MOPA inherits the frequency of the master laser. Hence the frequency actuators of the master laser can be used to change the frequency of the MOPA beam. The spatial mode of the laser is close to a fundamental Gaussian TEM00 mode.

As the detector currently used in the ALPS experiment has its sensitivity maximum in the visible spectral range the laser radiation has to be frequency doubled to 532nm. A high efficient periodically-poled KTP crystal (PPKTP) will be used as the nonlinear medium to perform this conversion. In a first experiment we will use a 2cm long PPKTP in a single path to generate approximately 4W of green radiation. Later we will use a cavity configuration to produce 20W of 532nm radiation.

Implementation

We will adopt a two phase approach to improve the sensitivity of the ALPS experiment. The goal of the first step is mainly to demonstrate the feasibility of the concept and to allow important noise and loss measurements in the ALPS environment which are essential as input parameters for the design of the second phase experiment. We expect that the sensitivity in the first phase will already be an improvement compared to the current ALPS experiment. Only small investments are required for this phase as the laser system can be provided as a short term loan by the AEI/LZH group and the frequency doubling as well as the servo electronics will be provided by the AEI. Depending of the stability of the set-up the first phase might already end with a data taking run with improved sensitivity. Early summer 2008 is the anticipated time frame for this phase.

Information on the cavity losses, the length fluctuations and drifts, the pointing fluctuations and other environmental parameters gained in the first phase will be used to design a high finesse ALPS cavity and to optimize the control systems for the second phase. A 35W laser dedicated to the ALPS experiment will replace the AEI/LZH laser on loan and the second harmonic generation will be improved by the installation of a cavity resonant for the fundamental beam. Our current best guess is that these measures will allow us to improve the design to achieve a circulating light power in the ALPS cavity of more than 10kW. This value might be reduced by the installation of phase plates required to match the axion and photon phase along the 4m path in the HERA magnet to probe higher mass axion-like particles. A tradeoff study is required between the additional optical losses introduced by the AR coated phase plates and the gain in the axion production rate due to the phase plates.

First phase

Fortunately the timing allows us to use a 35W laser system fabricated for a GWD prototype experiment for the first phase of cavity enhanced ALPS experiment. This laser will be frequency doubled in a single path PPKTP setup and 4W of green laser light will be injected into the ALPS cavity. This cavity will consist of the end mirror already installed in the HERA magnet and a curved mirror to be placed on the laser table. A moderate cavity Finesse will be used in this phase with an expected power buildup of about 90.

Figure 1 shows a schematic of the setup on the laser table. An electro-optical modulator will add radio-frequency phase modulation sidebands to the laser beam. These sidebands will be reflected by the input mirror of the ALPS cavity and will beat with the carrier light produced by the interference between the carrier field reflected by and leaking out of the ALPS cavity. A Faraday isolator protects the laser from light reflected by the ALPS cavity and will allow to detect this light on a resonant rf-photodiode to generate the Pound-Drever-Hall error signal. We will adjust the laser frequency to keep the cavity on resonance by feeding back to the fast and slow actuator of the master laser. This scheme has the advantage that we can use a stiff mirror mount for the curved ALPS cavity mirror and will furthermore achieve a unity gain frequency for the servo of approximately 30kHz (faster than what is achievable with a PZT actuator attached to the curved ALPS mirror). Several optical components in the setup are used for polarization and power control and the PPKTP has to be put into an oven to heat and stabilize it to an optimal phase matching temperature. Two steering mirrors are used to align the beam to the ALPS cavity. (Additional beam diagnostic components like power meters and CCD cameras are not shown).

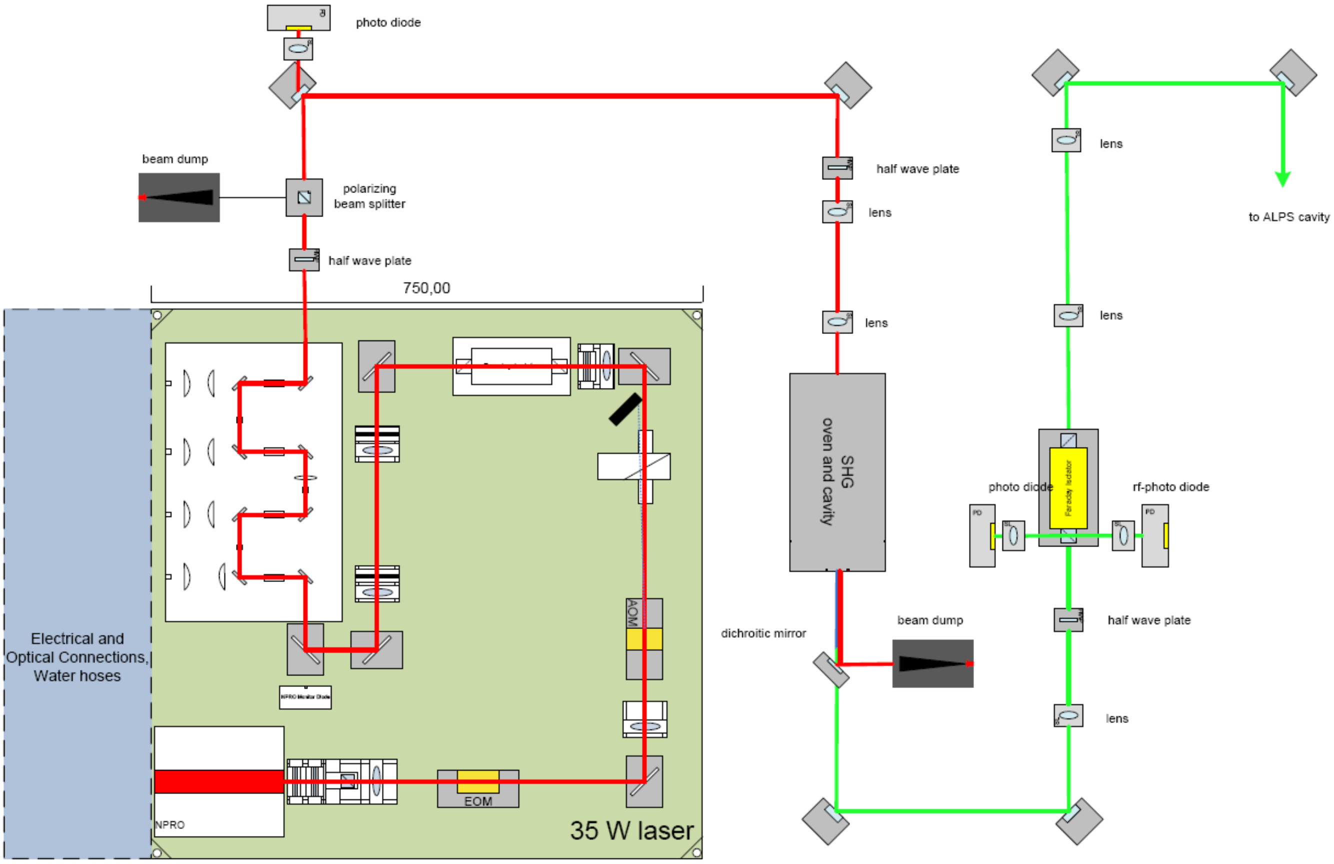


Figure 1: Schematic layout of the laser system

The ALPS cavity (see Figure 2) will be a linear cavity comprised by two mirrors. These are the input coupler M_c that will be placed on the optical table in the laser container and a second mirror near the middle of the HERA magnet, M_m. While M_c will be mounted on a stable conventional mirror mount to allow manual alignment of the cavity, M_m is already mounted in a way that allows remote actuation of the mirror angles. With these alignment options the Eigenmode of the cavity can be adjusted in a way required by the detector at the other end of the HERA magnet and simultaneously in such as to minimize deflection losses.

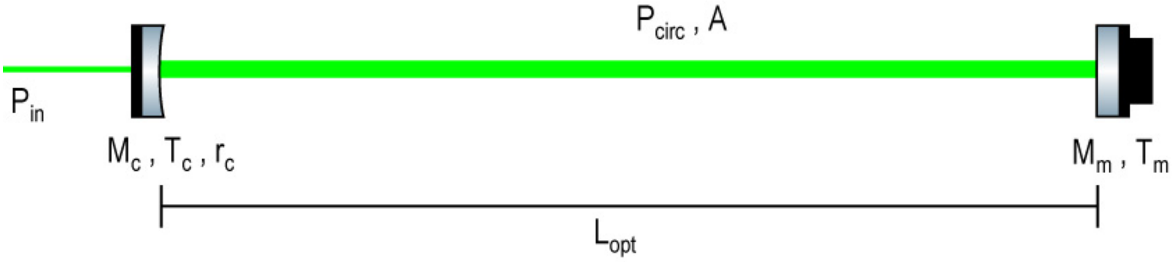


Figure 2: Schematic view of the ALPS cavity

To form a stable Eigenmode of the cavity, the radius of curvature of the coupler r_c and the distance between the two mirrors L_{opt} must fulfill a certain stability criterion. We choose r_c=-15m and L_{opt}=8.7m which results in an optical resonator Eigenmode that has a beam waist of 1120μm at M_m. A clear aperture inside the measurement tube of only 6.2mm in diameter is required for this mode to avoid significant losses due to clipping. Furthermore this cavity design prohibits simultaneous resonances of multiple low order TEM-modes which is important for an easy to use laser frequency control loop. (A plot of the beam propagation and of the resonance positions of higher order modes is given in the Appendix).

The most important property of the cavity for the ALPS experiment is its ability to enhance the circulating laser power on resonance. The power buildup is defined as the ratio of the circulating power P_{circ} and the incident power P_{in}. It is governed by the losses of the laser light during one roundtrip inside the cavity, A, as well as by the power transmissions of the two mirrors, T_c and T_m. The power transmission of the mirror currently installed inside the magnet T_m is approximately 300ppm In the current state of the experiment the roundtrip losses inside the measurement tube are quite high but by exchanging some components we are confident to reduce the single pass losses inside the cavity to a value of approximately A=1%. We have chosen a value of T_c=2% for the first phase to achieve a reasonable high power buildup P_{circ}/P_{in}=87 without having too complicated experimental conditions. Considering the planned input power of P_{in}=4W, we will have more than 300W of average laser power inside the cavity which is a factor of 23 higher than the average power used in earlier experiments.

Second phase

The main goal guiding the design of the second phase ALPS cavity is to have an as high as possible circulating power. To achieve this goal an optimization of the transmittance of the input mirror with regard to the losses (transmittance, absorption and scattering of the mirror in the HERA magnet, scattering and deflection on the beam path, scattering and absorption of the input mirror) is required. Figure 3 shows the dependence of the power buildup on the losses and the optical transmission of the incoupling mirror. For this simulation we assumed a transmission of M_m equal to the one of the already installed mirror of 300ppm. As one can see the optimal choice of the input mirror transmission depends on the losses in the cavity which are currently not well known but will be determined by the first phase.

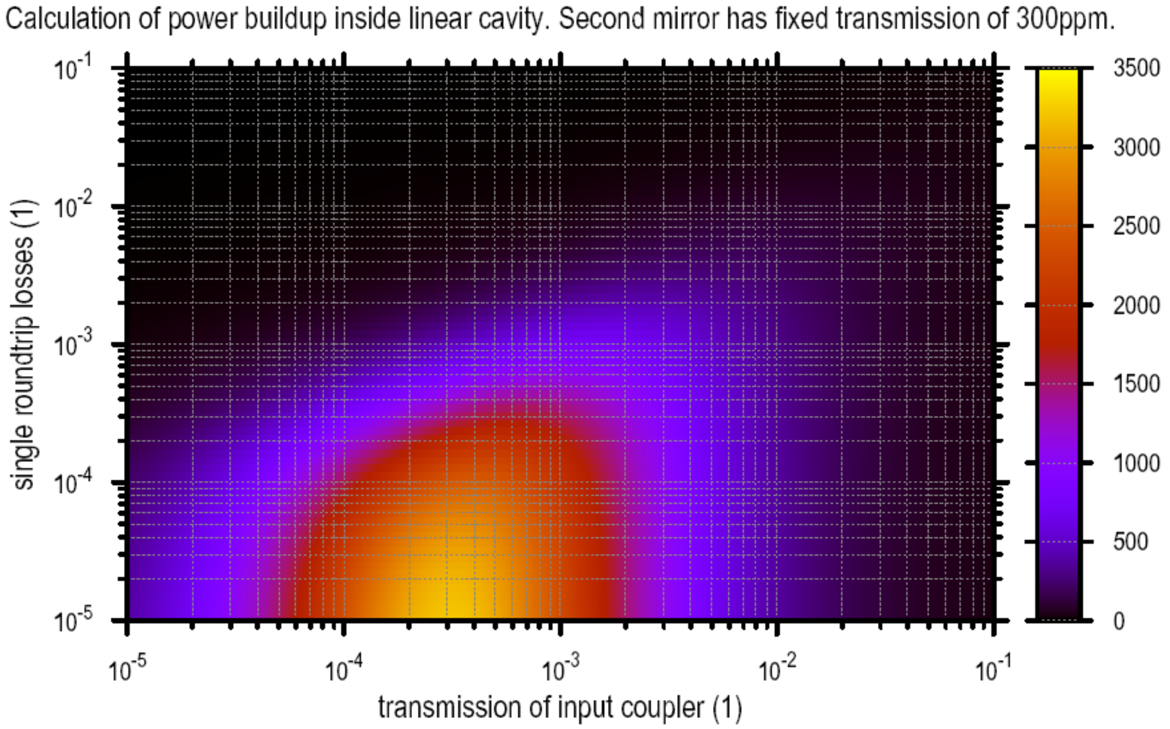


Figure 3: Dependence of the power buildup on the round trip losses and the transmission of the input mirror

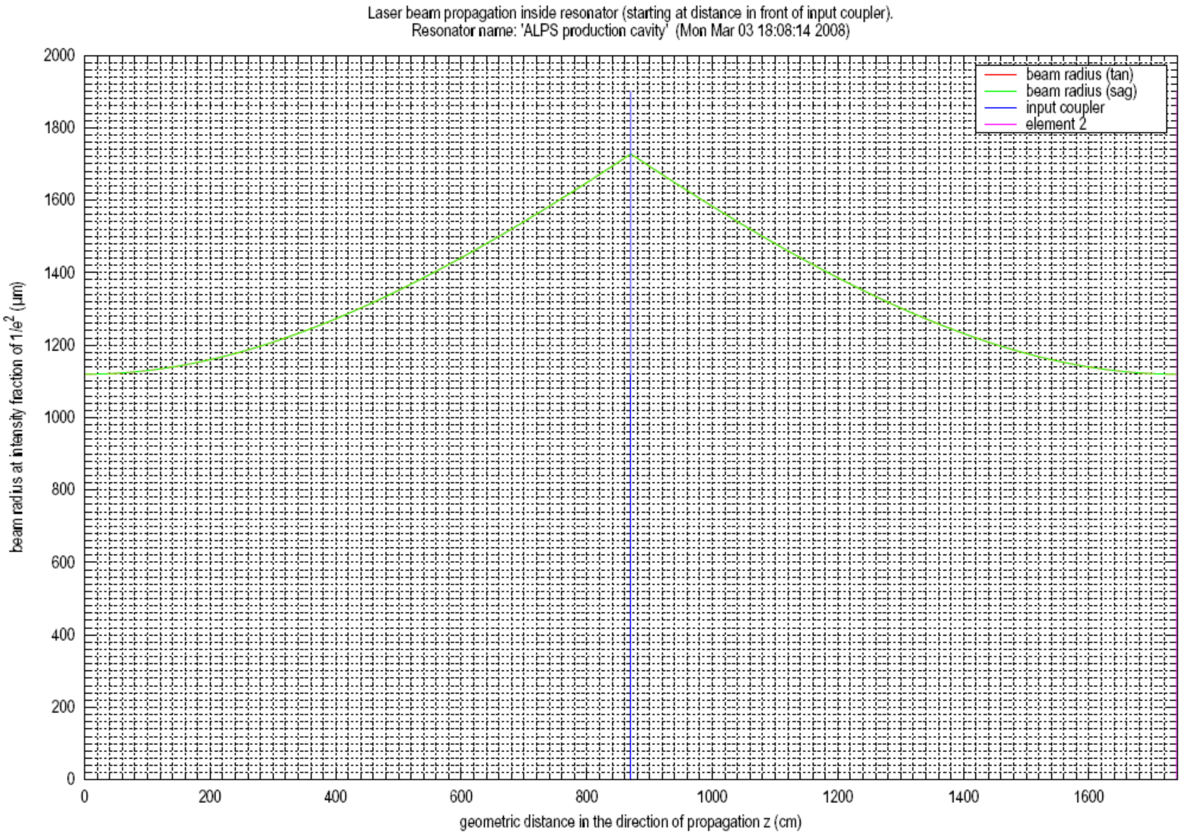
In addition to this optimization several other constraints have to be considered:

- the beam shape (diameter, wavefront curvature) on the laser table has to be prepared such as to match the Eigenmode of the cavity as good as possible
- the same holds for the angular and lateral beam alignment
- the radii of curvature have to be chosen such that higher order TEM_{mn} modes with a small m+n value have a large enough Gouy phase not to disturb cavity locking
- the free running laser frequency fluctuations have to be small enough compared to the linewidth of the cavity to allow lock acquisition
- the single mode, single frequency, linear polarized green laser beam should have low enough frequency fluctuations and drifts consistent with the range and speed of the servo actuators to allow fast lock acquisition and long lock durations

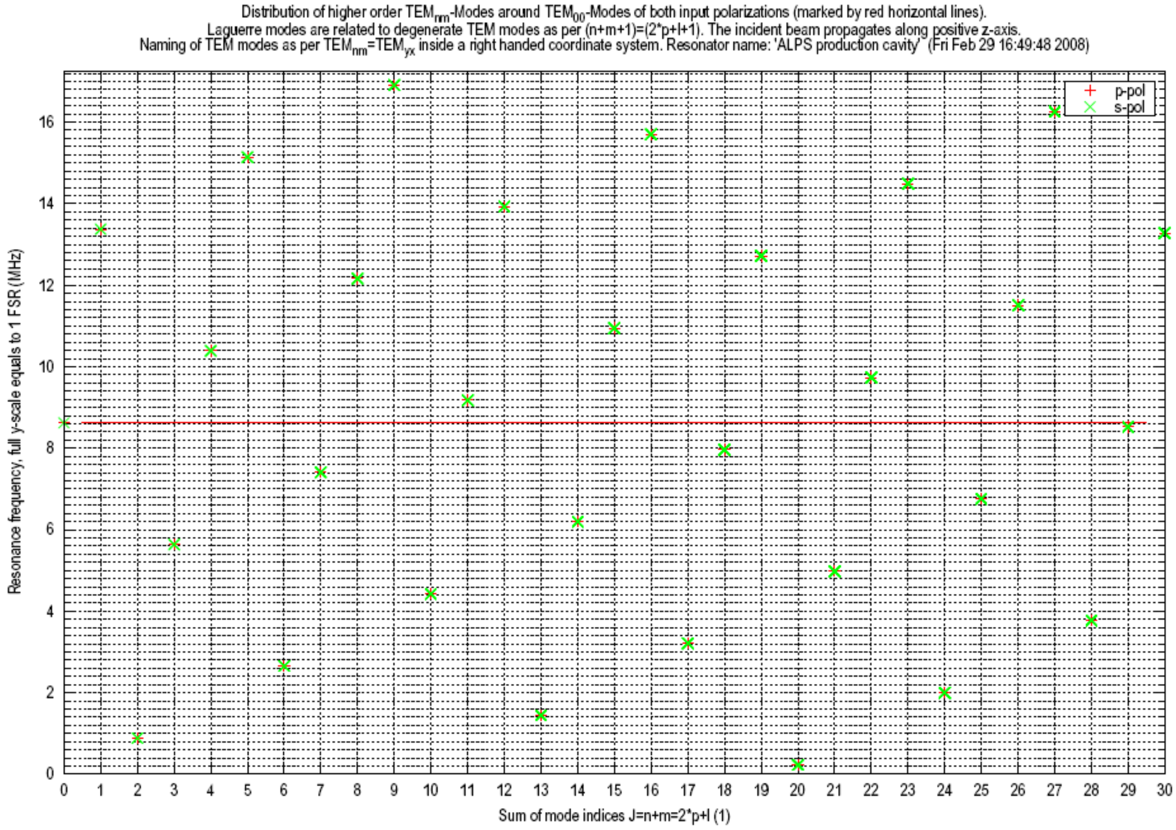
The second main change in the second phase is the use of a resonant cavity for the second harmonic generation to increase the green power. A similar system is currently in operation at the AEI to produce 7W of green light out of 10W infrared radiation. This resonant cavity requires a similar length control loop as the ALPS cavity does and a PZT actuator will be used to keep the cavity resonant. Scaling of the system currently in use at the AEI indicates that we should be able to achieve more than 20W of green light starting with 35W infrared radiation.

The design work of the second phase could start immediately after the test experiments of the first phase while a possible measurement phase is ongoing. After the production of the laser, the procurement of the ALPS cavity mirrors and the fabrication of the control electronics the commissioning work of the second phase could start as early as late fall 2008.

Appendix



Laser beam propagation inside resonator (starting at distance in front of input coupler).
Resonator name: 'ALPS production cavity' (Mon Mar 03 18:08:14 2008)



Distribution of higher order TEM$_{nm}$-Modes around TEM$_{00}$-Modes of both input polarizations (marked by red horizontal lines).
Laguerre modes are related to degenerate TEM modes as per (n+m+1)=(2*p+l+1). The incident beam propagates along positive z-axis.
Naming of TEM modes as per TEM$_{nm}$=TEM$_{yx}$ inside a right handed coordinate system. Resonator name: 'ALPS production cavity' (Fri Feb 29 16:49:48 2008)