Illuminating hidden Worlds

Particle Physics at lowest Energies

with the ALPS Experiment

A. Lindner, DESY

Tuesday Seminar,
DESY in Hamburg, 03 March 2010

HELMHOLTZ ASSOCIATION

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The Standard Model of Constituents and Forces

Constituents:

> Quarks

> Leptons

Forces:

> electromagnetic

> strong

> weak

> gravitation

http://www.gridpp.ac.uk/cubes/

Only the Higgs boson is missing!

The Standard Model of Constituents and Forces

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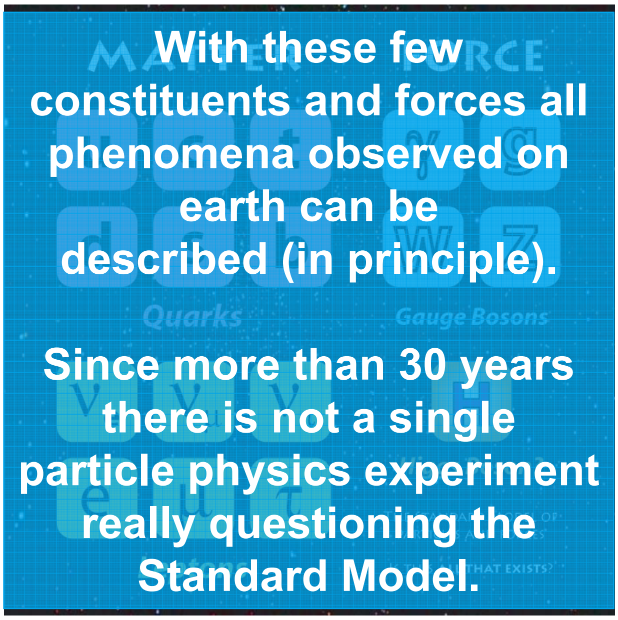


With these few constituents and forces all phenomena observed on earth can be described (in principle).

Since more than 30 years there is not a single particle physics experiment really questioning the Standard Model.

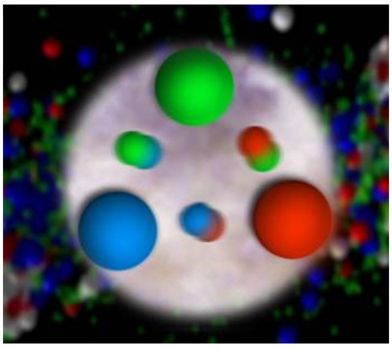
http://www.gridpp.ac.uk/cubes/

Only the Higgs boson is missing!

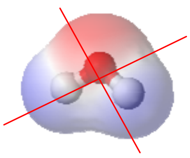
A Flaw in the Standard Model?

The neutron has a strange property:

It consists of three charged quarks, but does not show any static electric dipole moment.



http://www.lbl.gov/Science-Articles/Archive/sabl/2006/Oct/3.html



http://en.wikipedia.org

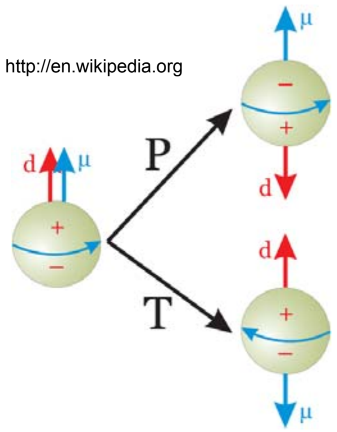
Why does the wave functions of the three quarks *exactly* cancel out any observable static charge distribution in the neutron?

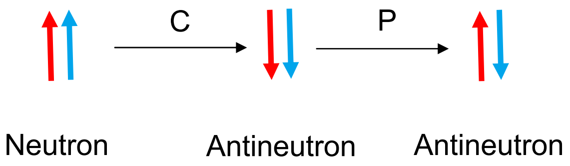
A Flaw in the Standard Model?

Electric and magnetic dipole moments of the neutron are related to fundamental symmetries:

> P (parity), T (time reversal) and C (charge conjugation) .

http://en.wikipedia.org





If the neutron has an electric dipole moment
in addition to the measured magnetic dipole moment, <u>C·P is not conserved</u>.
Both moments would change from parallelism to anti-parallelism.

The strong interaction conserves CP $\leftrightarrow$ no neutron electric dipole moment

A Flaw in the Standard Model?

However, C·P conservation is *not* an intrinsic feature of the theory of strong interactions (QCD) with massive quarks (as observed).

Naively one expects for the neutron electric dipole moment:

$d_{n\text{-}QCD} \sim 10^{-15}$ e·cm.

The data show:

$d_{n\text{-}data} < 10^{-26}$ e·cm.

How to explain the difference of at least 11 orders of magnitude?

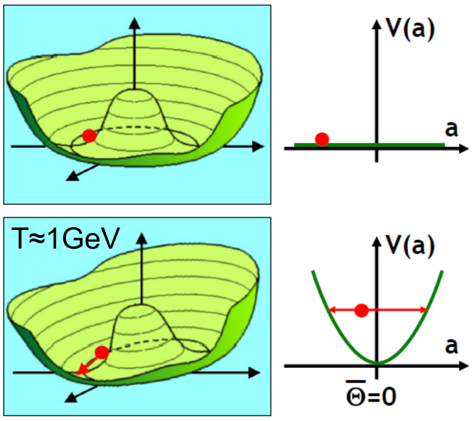
From a Flaw to a new Particle

The size of the C·P violation in QCD is described by a angle Θ. There are no theoretical bounds on Θ, but from the missing neutron dipole moment $\Theta < 10^{-9}$ is concluded.

Is this a "just-so", a "fine-tuning" of QCD? This would be very unsatisfying.

The theoreticians approach:
try to find a dynamic explanation!

Peccei-Quinn 1977:
Θ takes an arbitrary value by spontaneous symmetry breaking at a certain high energy scale f_a and roles down by non-perturbative QCD effects to its very small C·P conserving value observed in QCD at low energies.



S. Hannestaad, presentation at 5th Patras Workshop on Axions, WIMPs and WISPs, 2009

From a Flaw to a new Particle: the Axion

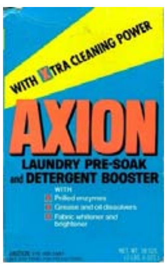
Wilczek and Weinberg independently noticed 1978:

The oscillations of Θ constitute an axion-field (christened by Wilczek).

Summary:

One can explain the C·P conservation in QCD if a new particle, the axion, exists.

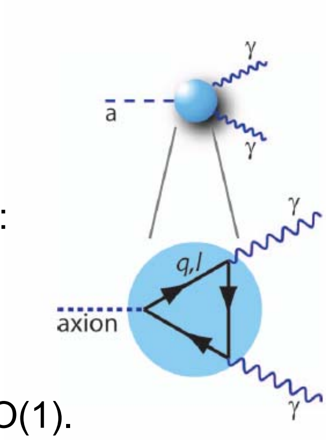
The axion "cleans" QCD.



ἀξιον = worthy, deserving

Properties of the QCD Axion

> The axion behaves like a light cousin of the π^0. It couples to two photons.



The Search for Axions, Carosi, van Bibber, Pivovaroff, Contemp. Phys. 49, No. 4, 2008

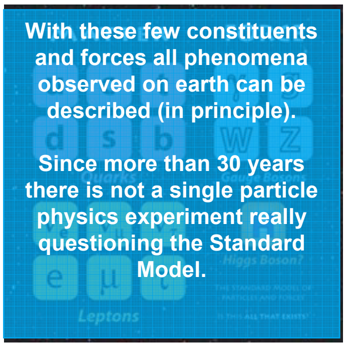
> Mass and the symmetry breaking scale f_a are related:
$m_a = 0.06\text{eV} \cdot (10^7\text{GeV} / f_a)$

> The coupling strength to photons is
$g_{a\gamma\gamma} = \alpha \cdot g_\gamma / (\pi \cdot f_a)$, where g_γ is model dependent and O(1).

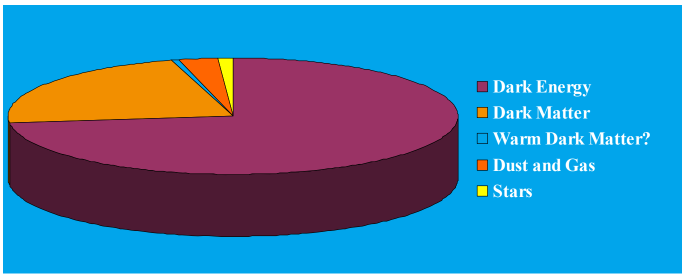
> The axion abundance in the universe is
$\Omega_a / \Omega_c \sim (f_a / 10^{12}\text{GeV})^{7/6}$.

The Standard Model beyond Earth

The great success on earth:

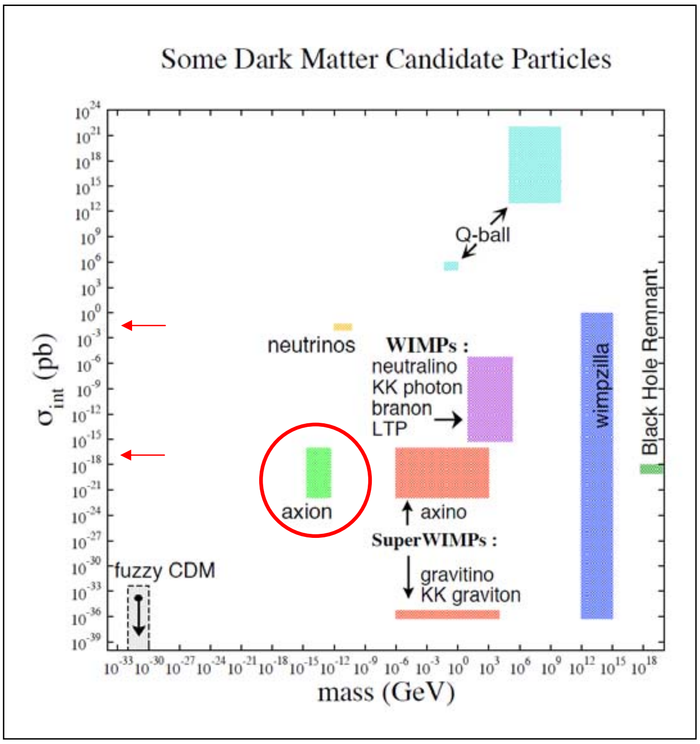


is questioned by astrophysics and cosmology:



The Standard Model (without axions!) describes only 4% of the matter-energy content of the universe!

Dark Matter could be Axions!



Due to their non-thermal production in the universe light axions would constitute *cold* dark matter.

Such axions couple extremely weakly to matter: the “invisible” axion.

The axion was *not* invented to solve the Dark Matter problem!

H. Baer, presentation at 5th Patras Workshop on Axions, WIMPs and WISPs, 2009

Alluring and challenging ….

The axion could solve two long-standing quests simultaneously:

> It could explain the CP conservation of QCD.

> A QCD axion in the mass region of 10^{-2} to 10^{-1} meV would be a “perfect” cold Dark Matter candidate.

Unfortunately this implies a very weak coupling to other stuff:
10^9GeV < f_a < 10^{12}GeV, compare electroweak scale of O(100 GeV)!
10^{-14} 1/GeV < $g_{a\gamma\gamma}$ < 10^{-12} 1/GeV

How to search for such an “invisible” axion?

This reminds on the history of the “undetectable“ neutrino postulated by Pauli in 1930 and discovered more than 20 years later.

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From Axions to ALPs and WISPs

There might be much more than a QCD axion:

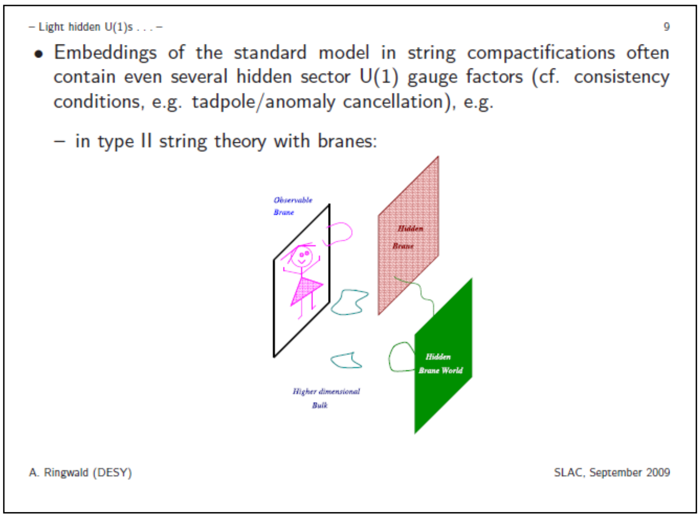
> ALPs: "axion-like particles"

String Axiverse
A. Arvanitaki, S. Dimopoulos, S. Dubovsky, N. Kaloper, and J. March-Russell,
arXiv:0905.4720 [hep-th]
String theory suggests the simultaneous presence of many ultralight axions, possibly populating each decade of mass down to the Hubble scale 10^{-33}eV. Conversely the presence of such a plenitude of axions (an "axiverse") would be evidence for string theory, ...

> WISPs, Weakly Interacting Sub-eV Particles,
(axions and ALPs, hidden sector photons, mini-charged particles) occur naturally in string-theory motivated extensions of the Standard Model

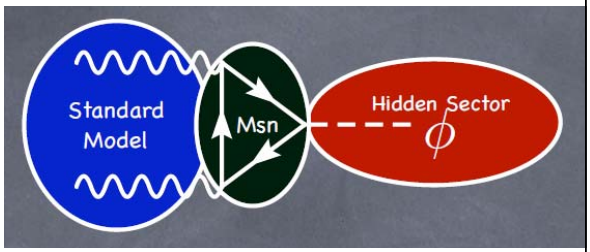
Naturally Light Hidden Photons in LARGE Volume String Compactifications
M. Goodsell, J. Jaeckel, J. Redondo and A. Ringwald,
arXiv:0909.0515 [hep-ph], JHEP 0911:027,2009
Extra "hidden" U(1) gauge factors are a generic feature of string theory that is of particular phenomenological interest. They can kinetically mix with the Standard Model photon and are thereby accessible to a wide variety of astrophysical and cosmological observations and laboratory experiments.

WISPs: Illuminating Hidden Worlds?


– Light hidden U(1)s . . . – 9

- Embeddings of the standard model in string compactifications often contain even several hidden sector U(1) gauge factors (cf. consistency conditions, e.g. tadpole/anomaly cancellation), e.g.
  - in type II string theory with branes:

A. Ringwald (DESY) SLAC, September 2009



> Very massive messengers may communicate between “our” Standard Model world and hidden sectors of a stringy universe.

  In this sense WISP searches try to illuminate hidden worlds and probe very high energy scales.

Summary on Motivation

> The axion remains interesting as a
  - solution to the CP conservation of QCD,
  - candidate for Dark Matter.

> The might be a plenitude of Weakly Interacting Sub-eV Particles
  - occurring naturally in string-theory inspired extensions of the Standard Model,
  - opening a window to physics beyond the TeV scale.

> Theory starts to develop detailed scenarios and predictions for WISPs to be probed by experiments.
  - Not only detections, but also upper-limits on WISP productions might become important ingredients for theory.

An Experimentalist's Motivation: Just Coincidences?

- Neutrinos have masses at the meV scale.
- The density of Dark Energy in our Universe is 10^{-29}g/cm^3, being equivalent to $\rho_{DE} \cong (2\ \text{meV})^4$.

The cosmological constant problem, *S. Weinberg*, Rev. Mod. Phys. 61, 1–23 (1989)	ute to the effective cosmological constant. In order to keep $\rho_V < 10^{-48}$ GeV^4, we need the scalar field adjustment to cancel the effect of gravitational and electromagnetic field fluctuations down to frequencies 10^{-12} GeV; for this purpose we must have $m_\phi < 10^{-12}$ GeV. A field this light will have a macroscopic range: $\hbar/m_\phi c \gtrsim 0.01$ cm.

- Today's energy density of the universe is about $(\text{meV})^4$.

Does this hint at new physics at the meV scale?

Presumably, LHC & Co. results will not explain these phenomena.

Let's strive for dedicated experiments!

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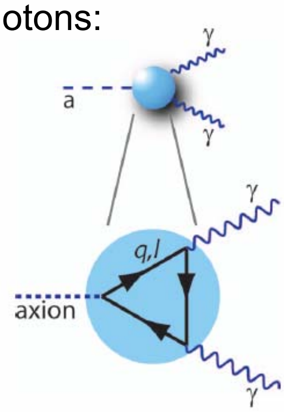
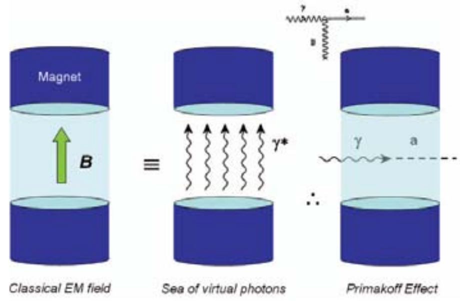
How to search for “invisible” WISPs: exemplary Basics

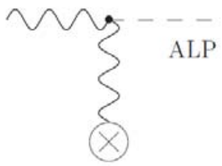
> Neutral scalar or pseudoscalar WISPs couple to two photons:



> One of these photons can be provided by an electric or magnetic field: exploit the Primakoff effect



The Search for Axions,
Carosi, van Bibber, Pivovaroff,
Contemp. Phys. 49, No. 4, 2008



➢ WISPs can be produced by light shining into a magnetic field.

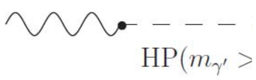
➢ WISPs entering a magnetic field can convert into a photon.

The Search for Axions, Carosi, van Bibber, Pivovaroff, Contemp. Phys. 49, No. 4, 2008

How to search for “invisible” WISPs: exemplary Basics

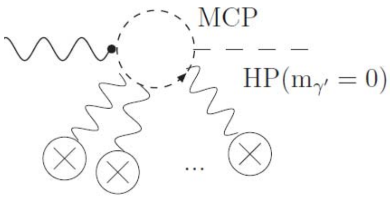
> Neutral scalar or pseudoscalar WISPs: exploit the Primakoff effect

> Neutral vectorbosons (“hidden sector photons” HP): exploit mixing with “ordinary” photons.



How to search for “invisible” WISPs: exemplary Basics

- Neutral scalar or pseudoscalar WISPs: exploit the Primakoff effect
- Neutral vectorbosons (“hidden sector photons” HP): exploit mixing with “ordinary” photons.
- Minicharged particles (MCP, about 10^{-6} e): “loop effects”.



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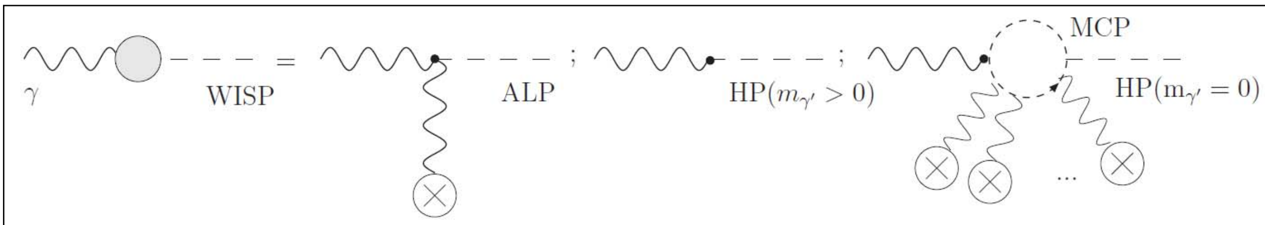


Axion-Like Particles, *Hidden Photons,* *MiniCharged Particles*

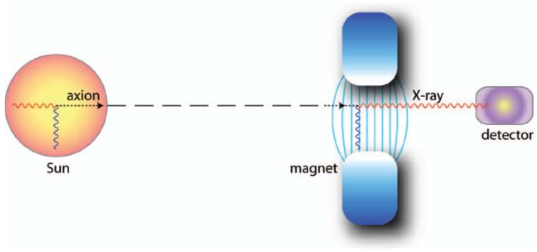
How to search for “invisible” WISPs: Astrophysics

> Indirect:
WISPs would open up new energy loss channels for hot dense plasmas

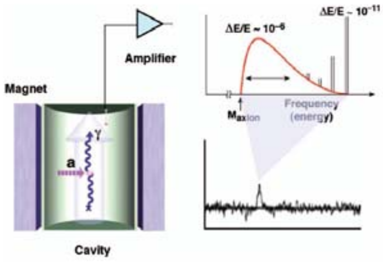
- stringent limits on WISP characteristics from the lifetime of stars, length of neutrino pulse from SN and cosmic microwave background radiation for example.

> Direct:

- Search for axions from the sun (CAST at CERN)



- Search for halo dark matter axions (ADMX at Livermore)



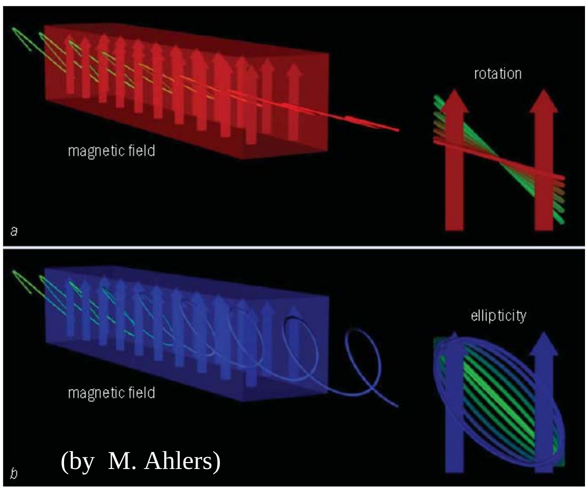
The Search for Axions, Carosi, van Bibber, Pivovaroff, Contemp. Phys. 49, No. 4, 2008

How to search for “invisible” WISPs: Lab Experiments

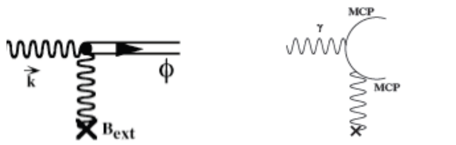
> (Some) WISPs could manifest themselves in fifth force experiments.

> Experiments with intense laser beams providing very high photon number fluxes or extremely good control of beam properties.

- Indirect: search for polarization effects

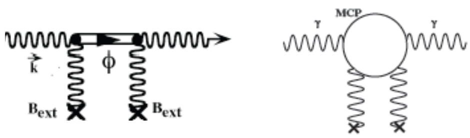


rotation: dichroism (selective absorption) due to real WISP production



different conversion of light polarized ∥ and ⊥ to the magnetic field into WISPs.

ellipticity: birefringence (different light velocities) due to virtual WISP production



QED: Δn (⊥ - ∥) = $3.6 \cdot 10^{-22}$ (9.5 T @ LHC dipole)

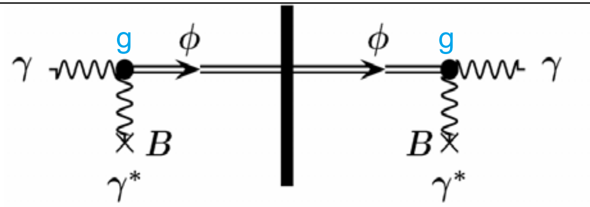
G. Cantatore, 5th PATRAS workshop 2009,
see http://axion-wimp.desy.de/e30/e52240/e54433/GiovanniCantatore.pdf

How to search for “invisible” WISPs: Lab Experiments

> (Some) WISPs could manifest themselves in fifth force experiments.

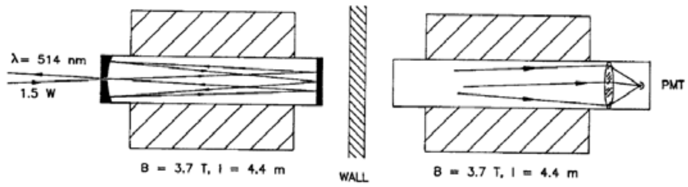
> Experiments with intense laser beams providing very high photon number fluxes or extremely good control of beam properties.

- More direct: “light-shining-through-a-wall” (LSW)



Okun 1982, Skivie 1983, Ansel‘m 1985, Van Bibber et al. 1987

Note:
$P_{\gamma\to\Phi\to\gamma} \sim g^4$



G. Ruoso et al.
(BFRT Experiment),
Z. Phys. C 56 (1992) 505

Searching for ALPs: The Status before 2005

> Accelerator based experiments searching for the QCD axion (or ALPs) quickly showed in the 1980‘ties that such particles, if they exist at all, have to be very light and “invisible”.

> BFRT searched in 1992 for polarization effects and LSW, but did not find any hint for a new particle.
A limit of $g_{a\gamma\gamma} < 10^{-6}$ 1/GeV was achieved for $m_a < 1$meV.

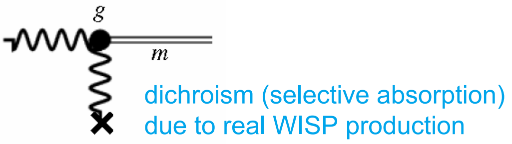
> Limits from astrophysics gave $g_{a\gamma\gamma} < 10^{-10}$ 1/GeV excluding a QCD axion for approximately $m_a > 1$eV.

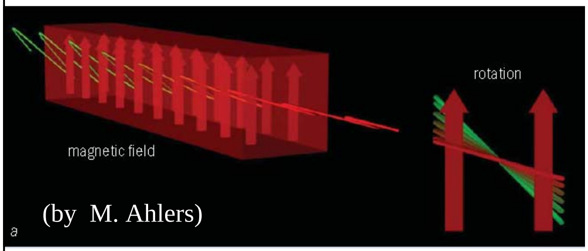
> However, only a QCD axion in the mass region of 10^{-5} to 10^{-4} eV would be a “perfect” cold Dark Matter candidate. This implies a very weak coupling of 10^{-14} 1/GeV $< g_{a\gamma\gamma} < 10^{-12}$ 1/GeV.

Note:
$P_{\gamma\to\Phi\to\gamma} \sim g^4$

A hopeless situation?!

The Return of the Axion: PVLAS 2005 / 2006





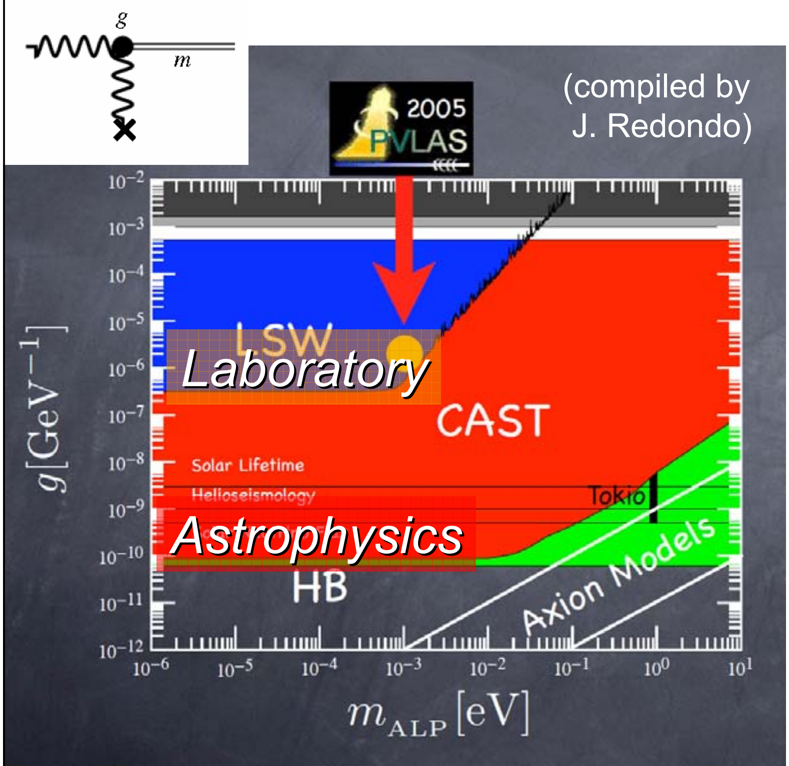
PVLAS 2005/2006:

Experimental Observation of Optical Rotation Generated in Vacuum by a Magnetic Field

E. Zavattini et al., Phys. Rev. Lett. 96, 110406 (2006)

…The relevance of this result in terms of the existence of a light, neutral, spin-zero particle is discussed…

The Return of the Axion: PVLAS 2005 / 2006



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…The relevance of this result in terms of the existence of a light, neutral, spin-zero particle is discussed…

This was in apparent contradiction to limits from astrophysics!

The Return of the Axion: PVLAS 2005 / 2006

Consequences from the unexpected PVLAS result:

> Strong push for many experiments:

- LSW:
  ALPS@DESY, BMV@Toulouse, GammeV@FNAL, LIPSS@JLab, OSQAR@CERN
- Polarization:
  BMV@Toulouse, OSQAR@CERN, PVLAS@Trieste, Q&A@Taiwan

> Strong push for theoretical activities:

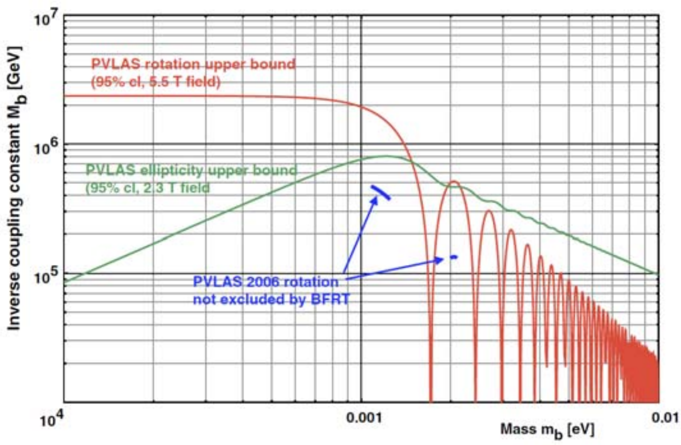
- Masso-Redondo model:
  Different effective theories at keV energies (stars) and at low energies (laboratory),
  WISP production might be suppressed in stars,
  but not in "low energy" environments in the laboratory.
- WISPs occur naturally in string-theory based extensions of the Standard Model.
  There might be much more than the QCD axion!

The discovery of the "low energy frontier"!

The Setback in 2007

> There is *no* new phenomenon like the one published by PVLAS in 2006:

New PVLAS results and limits on magnetically induced optical rotation and ellipticity in vacuum
E. Zavattini et al.,
Phys.Rev.D77:032006 (2008)



> In spite of this and other negative results of experimental searches, the field is still alive due to the theoretical insights discussed above.

The Survival of the “Low Energy Frontier”

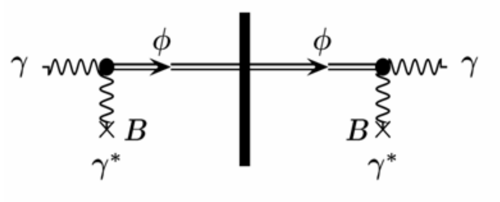
> The discovery of WISPs may be “just around the corner”.

> Astrophysics and laboratory experiments complement each other.

> Probing the QCD axion remains a challenge.

> LSW experiments offer the most promising perspectives to probe for meV WISPs in the laboratory.

- The production (and re-conversion) of WISPs takes place in a coherent fashion.

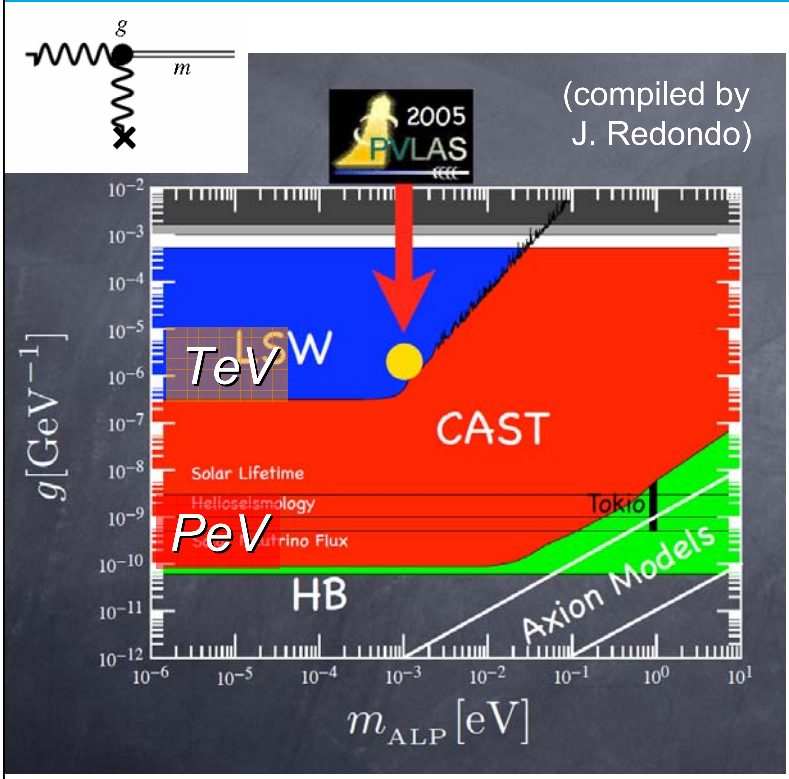


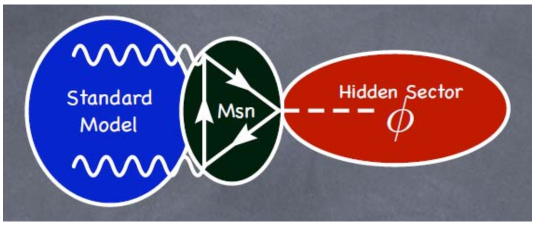
For ALPs (Φ):

$$P_{\gamma\to\phi}(B,\ell,q) = \frac{1}{4}\,(g\,B\,\ell)^2\;F(q\ell) \qquad F(q\ell) = \left[\frac{\sin\left(\frac{1}{2}q\ell\right)}{\frac{1}{2}q\ell}\right]^2$$

q = $p_\gamma - p_\Phi$
l: length of B field

Note: a meV Physics Window to highest Energies?





$M_{MSN} \sim \alpha / (\pi g) \cdot O(1)$

In the “hidden sector” models the existing limits probe messenger masses at TeV to PeV scales!

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ALPS @ DESY in Hamburg

The ALPS Project

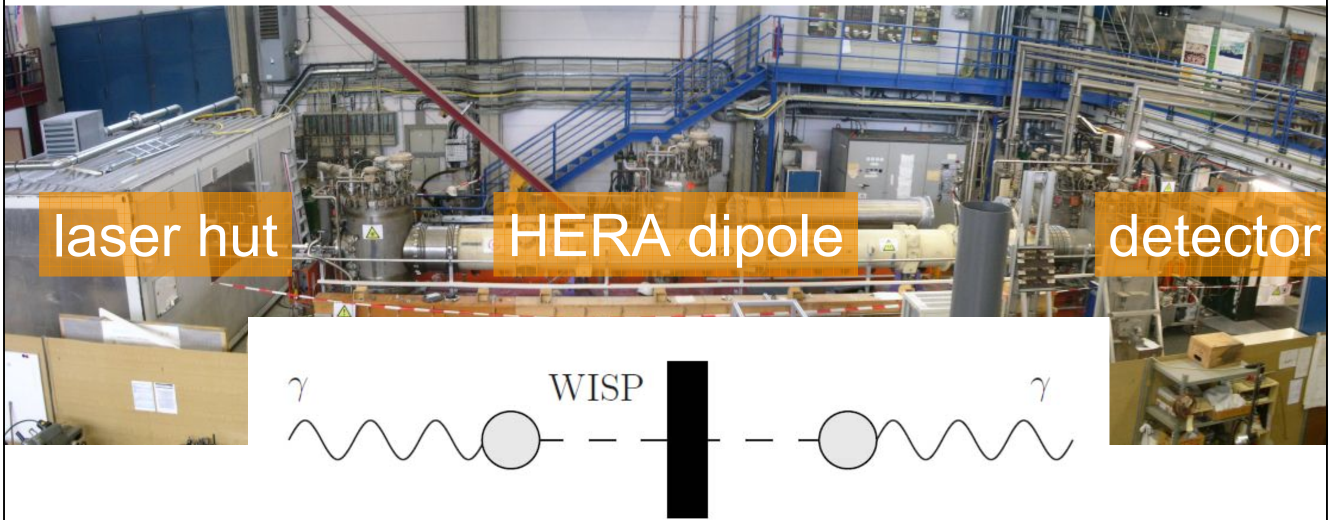
Axion-Like Particle Search @ DESY

The ALPS Project

Any Light Particle Search @ DESY

The ALPS Project

Any Light Particle Search @ DESY



A “light-shining-through-a-wall” experiment

The ALPS Project

Any Light Particle Search @ DESY

- DESY
- Max Planck Institute for Gravitational Physics (Albert Einstein Institute), and Institute for Gravitational Physics, Leibniz University Hannover
- Laserzentrum Hannover
- Hamburger Sternwarte

Leibniz Universität Hannover

LZH LASER ZENTRUM HANNOVER e.V.

Universität Hamburg

Three main ALPS Components

> Sensitive detector:
CCD
(determines wavelength of laser light)

> Strong magnet:
HERA dipole
(unfortunately just one)

> Powerful laser:
optical cavity to recycle laser power
(high quality laser beam)

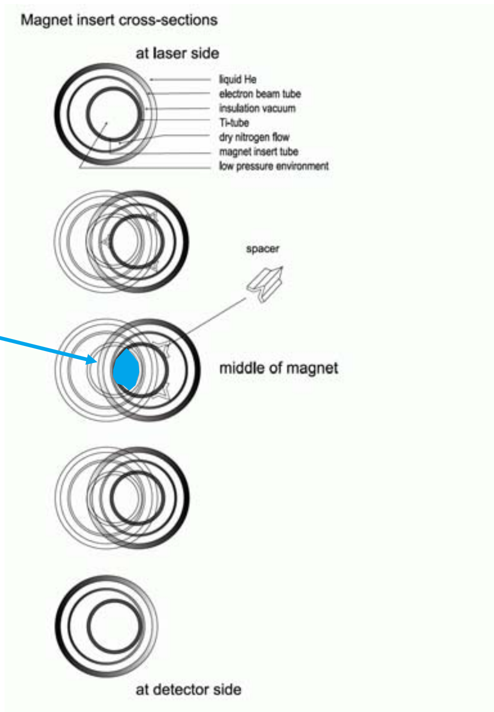
Severe Experimental Constraints

> Just one HERA dipole magnet:
Wall and one mirror are to be placed in the middle of the magnet.
The mirror is to be steered remotely.

> The beam tube inside the dipole is bent.

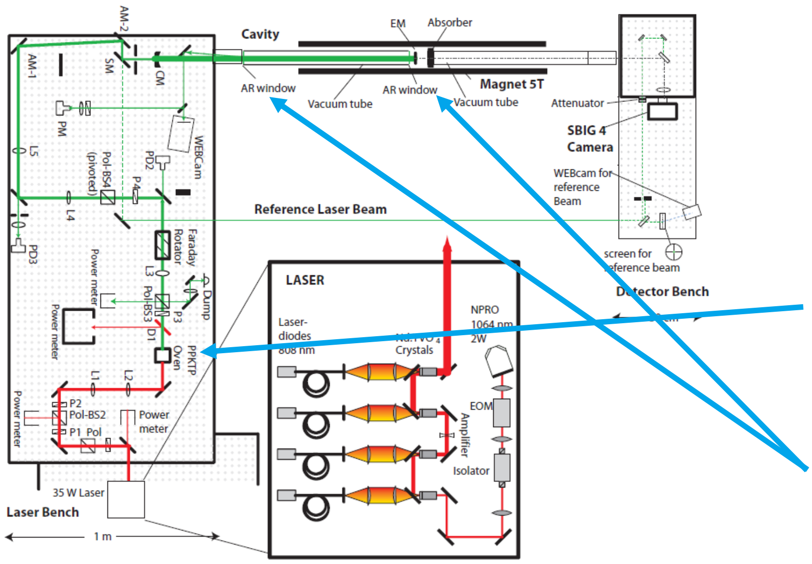
- Clear aperture only 14 mm (vertical) on a length of 8.6 m.
- A laser with very excellent beam quality (Gaussian beam profile) is required.

Essential:
Collaboration with members of the gravitational wave antenna community.



ALPS : first Operation of an optical Resonator

> Set-up for data published in NIM A, doi:10.1016/j.nima.2009.10.102
(Resonant laser power build-up in ALPS—A “light shining through a wall” experiment)



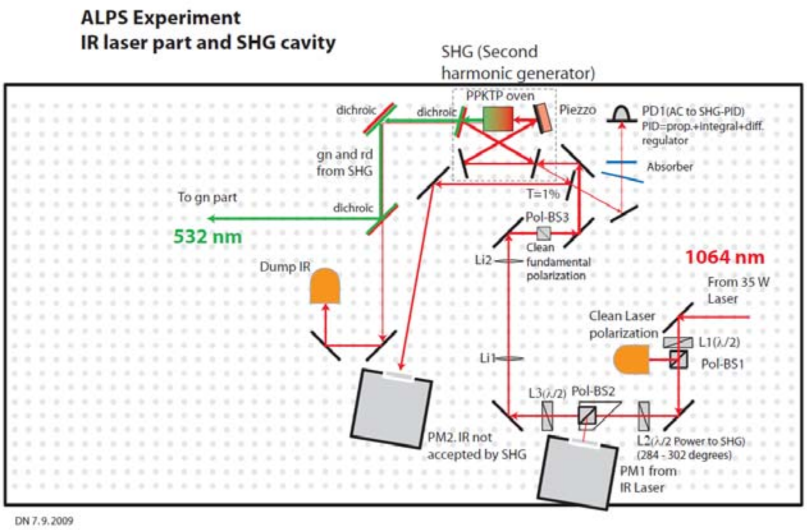
First successful operation of an optical resonator in a LSW experiment as a proof of principle!
The main limitations were:

The conversion of 1064 nm to 532 nm light was somewhat inefficient:
0.8 W out of 35 W (2.2%).

The power built-up in the resonator was limited by the transparency of the windows sealing the vacuum tubes.

ALPS Upgrades since Spring 2009: Laser

> Upgrade 1 for data taking August to December 2009:



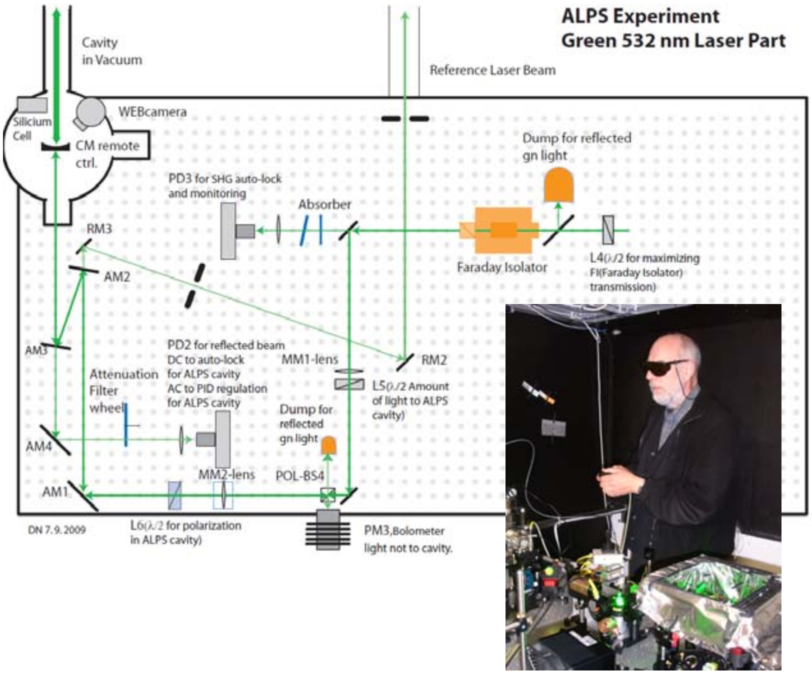
Improved frequency doubling of laser light by use of a second resonator:
now 5 W out of 10 W are achieved (50%).

The power was not increased further in order not to endanger the PPKTP crystal (would cause delay of about two months).

Later it turned out that this is not limiting the whole system.

ALPS Upgrades since Spring 2009: Laser

> Upgrade 2a for data taking August to December 2009:



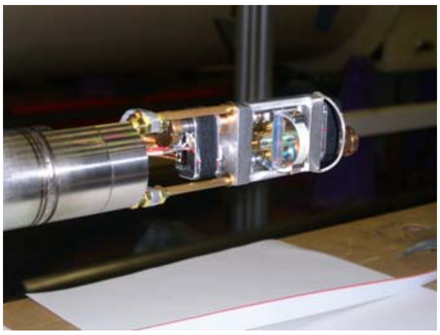
Get rid of AR windows by including the cavity mirrors into the vacuum of the laser beam tube:

The vacuum system was extended up to the laser bread-board and the coupling mirror for the resonator place in a vacuum tank.

This complicated the alignment and operation of the resonator significantly (no direct access anymore, only remote controls and web-cams).

ALPS Upgrades since Spring 2009: Laser

> Upgrade 2b for data taking August to December 2009:



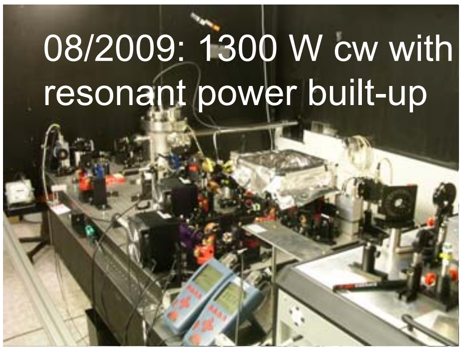
Get rid of AR windows by including the cavity mirrors into the vacuum of the laser beam tube:

The mirror holder in the centre of the ALPS magnet attached to the laser side vacuum tube was replaced by a new much smaller holder which slides into the tube.

No properly suited small motors (vacuum + 5 Tesla!) are available, but fortunately own improvements of magnet-suited squiggle motors work!

ALPS Upgrades since Spring 2009: Laser

> Result of laser upgrades for data taking August to December 2009:



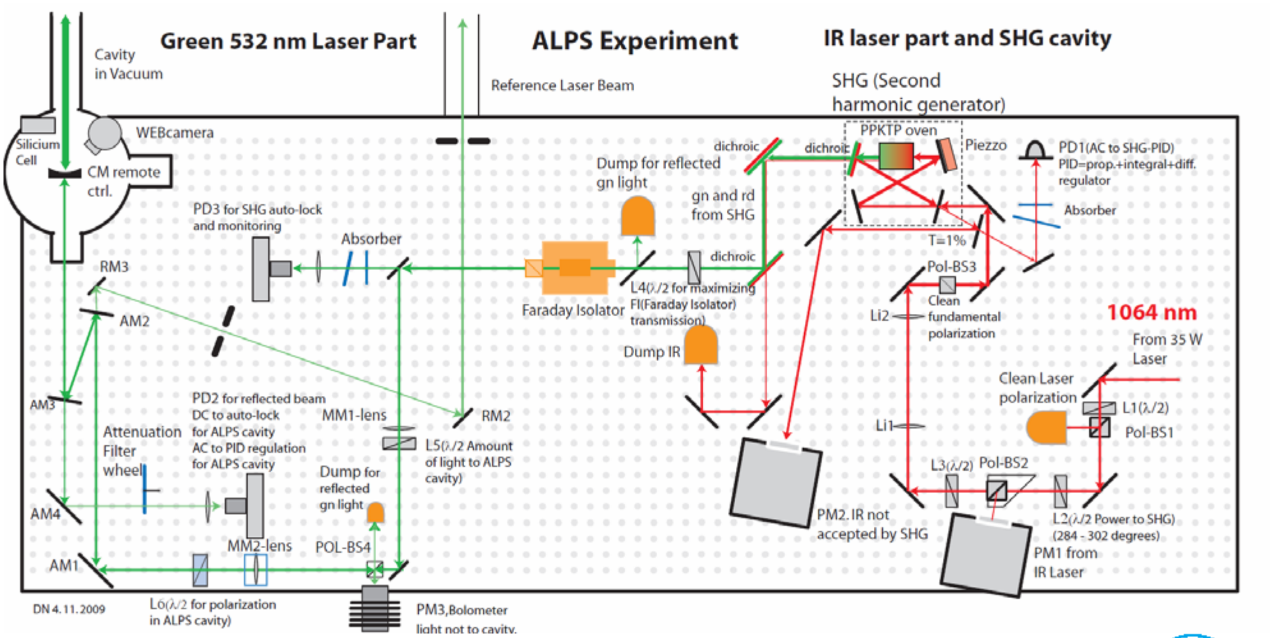
The 1300 W laser power is achieved from 4.4 W built-up in the resonator by a factor of 300.

The power is limited by the lifetime of the mirrors in vacuum (10-30 h) due to heating. However, a significant further improvement would also require investments into beam stabilization and new locking electronics.

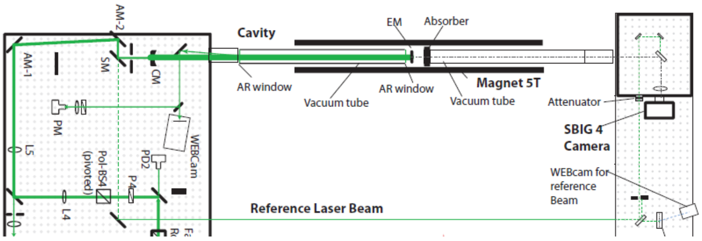
1300 W is much more than we ever dreamt of!

The new ALPS Laser System

> We are running a quite complex and delicate apparatus!



ALPS at Work

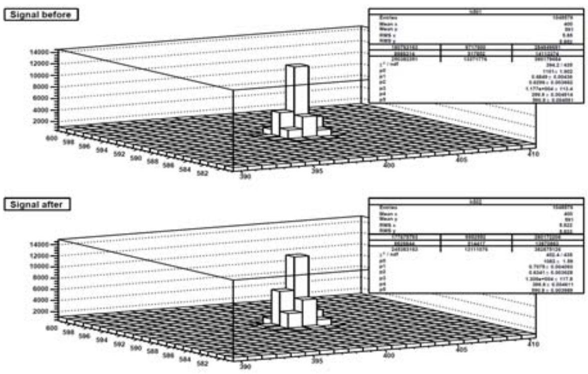


Steps of data taking:

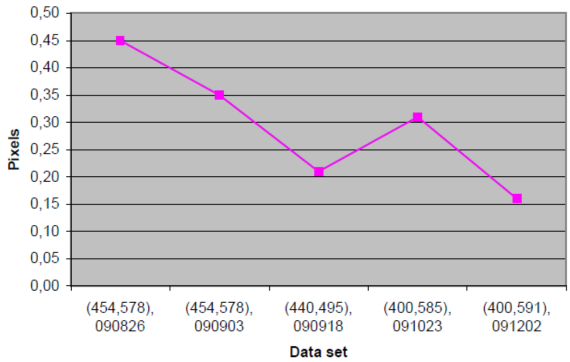
1. Test alignment with open detector tube and fraction of laser light passing the mirror (10^{-4}).
2. Demount detector and detector tube, close tube and reinstall all.
3. Take data (1h CCD exposures).
4. Demount detector and detector tube, open tube and reinstall all.
5. Test alignment like in step 1.

Stability of Beam Spot Position

Signal before and after a data run (Ar, hidden photon search).

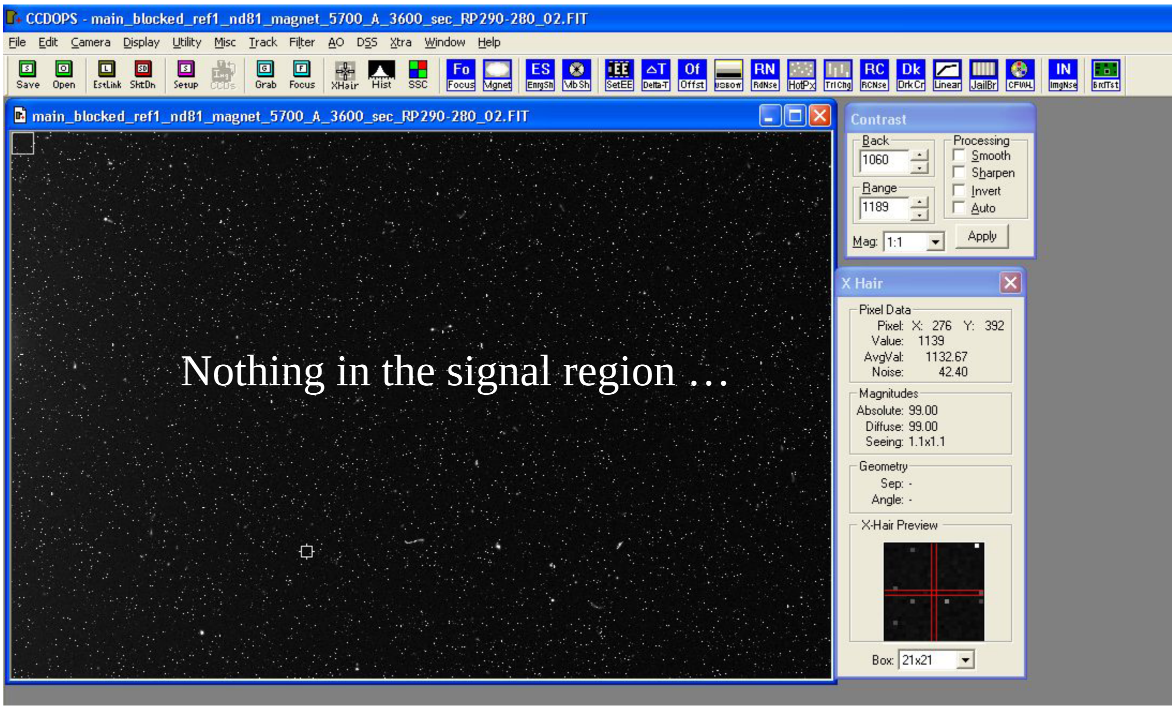


Peak position difference (before / after each run)

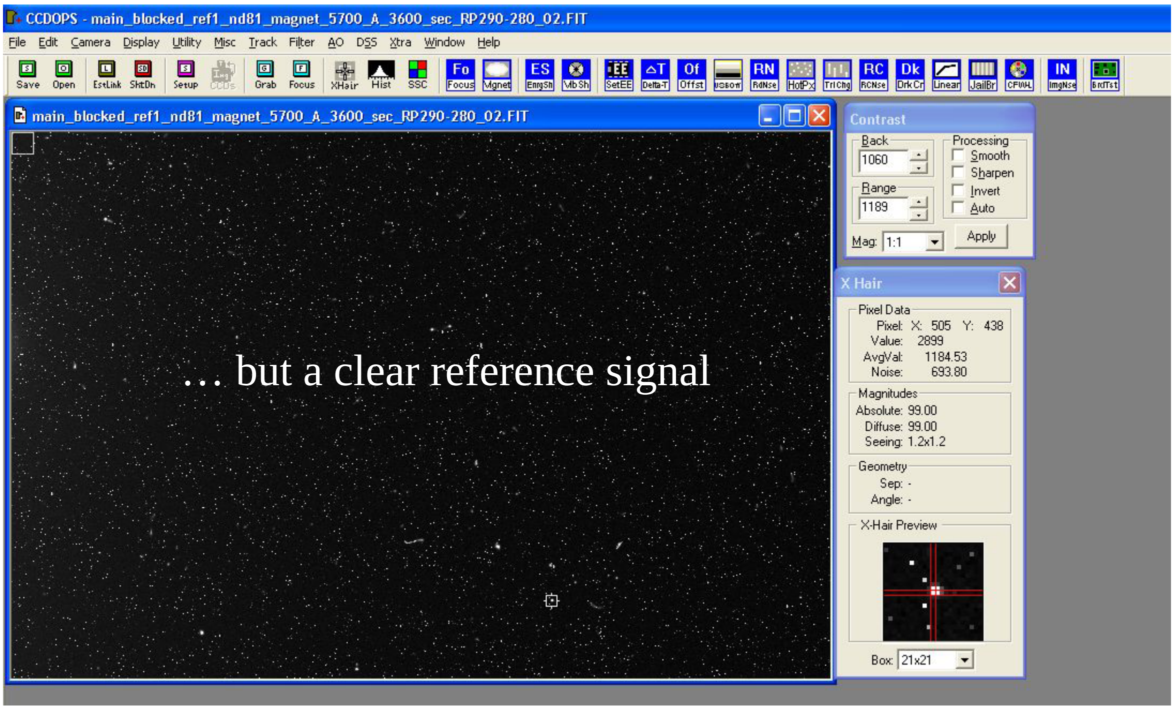


Peak position of beam spot does not move more than 0.5 pixels (6.5 μm).

One Data Frame (SBIG ST-402)

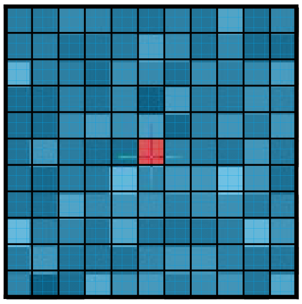


One Data Frame (SBIG ST-402)



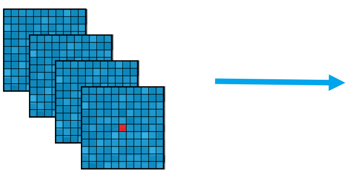
Principles of the Data Analysis

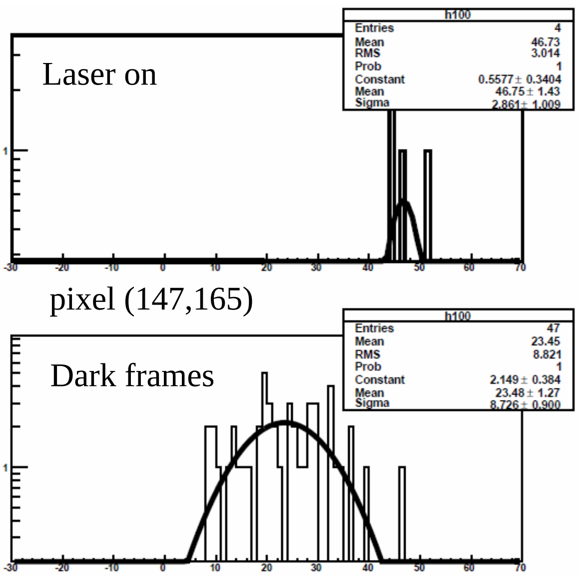
- The data consist of CCD frames with an exposure of one hour.
- The photons from reconverted WISPs would arrive in a known CCD pixel (3x3 hardware pixels combined into one “software” pixel).
- To search for WISPs, the value of the specific pixel is compared between data frames (where on expects WISPs) and dark frames (where no WISPs are expected, for example camera shutter closed).
- To get rid of the frame-to-frame fluctuation of the CCD camera (a *PIXIS 1024B* for the final data runs), the difference between the signal pixel and the average of the surrounding 120 pixels of an 11·11 pixel grid is determined for each frame.

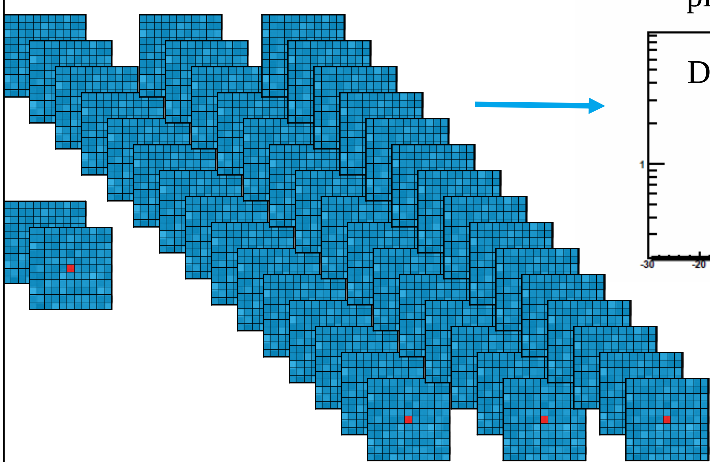


A Glimpse into the Data Analysis

- Each 1 h exposure results in one entry (ADU value of the signal pixel) into the histogram:



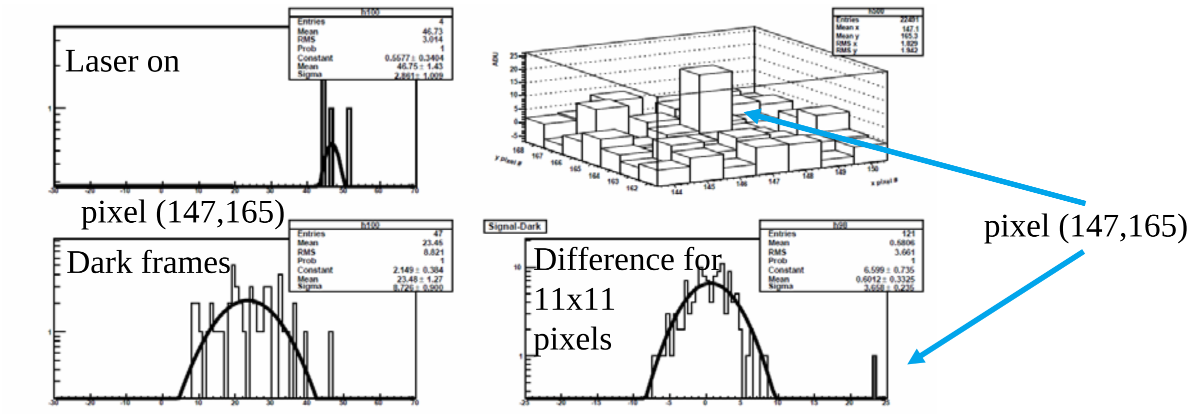




Compare mean ADU for “Laser on” and “Dark frames”.

A Glimpse into the Data Analysis

> Test the CCD and the data analysis with a photon beam of extremely low intensity: between 5 mHz and 50 mHz.



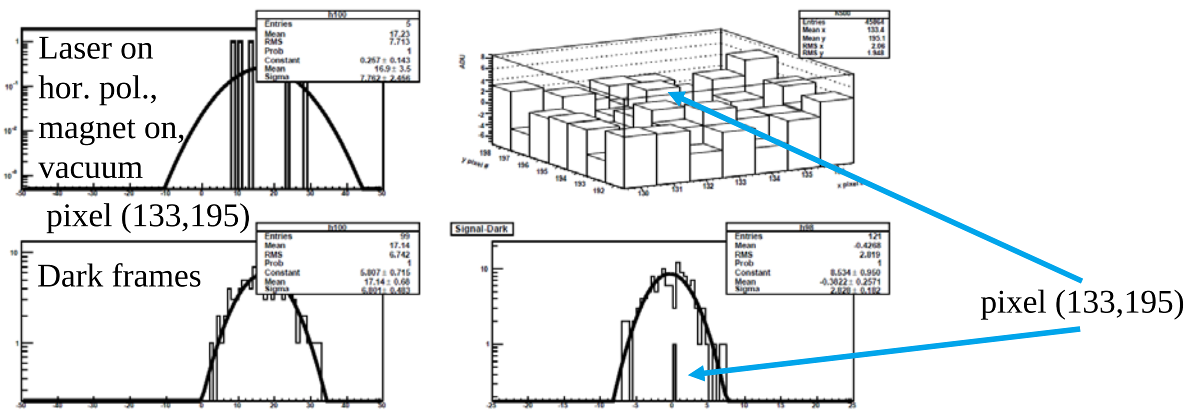
From Gaussians fitted to the data:

Δmean	Δwidth
23.27±3.20	-5.86±3.20

A photon flux of (7.9±1.2) mHz ($3\cdot10^{-21}$ W) is detected which agrees nicely to the expectation.

A Glimpse into the Data Analysis

> Example for a data run:



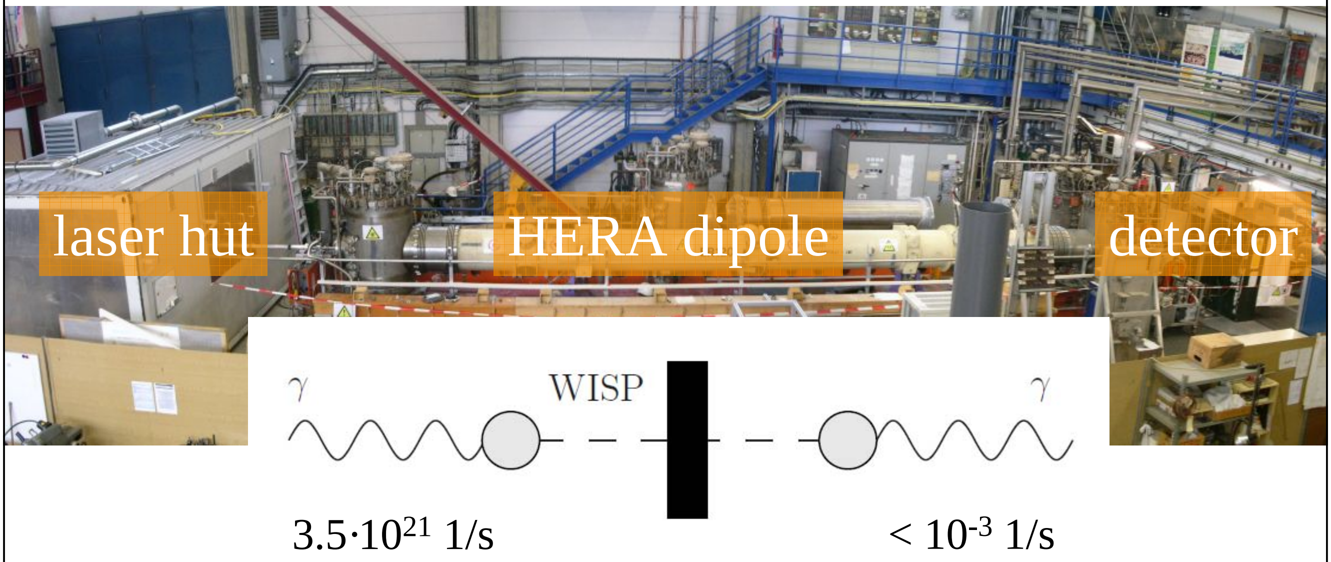
From Gaussians fitted to the data:

Δmean	Δwidth
-0.24±3.54	0.96±2.50

In none of the preliminary data analyses any evidence for WISP production shows up.

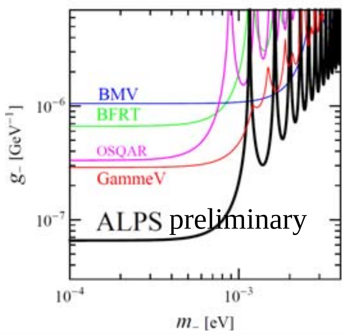
Preliminary ALPS Results

> Unfortunately, no light is shining through the wall!

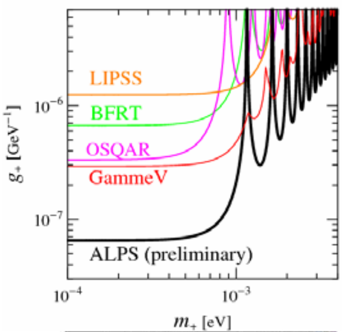


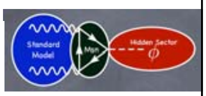
Preliminary Results for the Vacuum Data

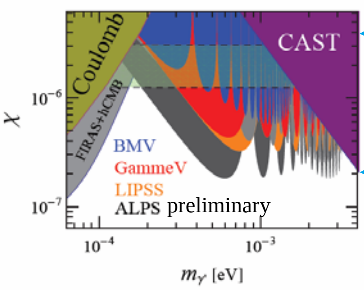
> ALPS is the most sensitive experiment for WISP searches in the laboratory. For axion-like particles, ALPS probes physics at the “multi-10-TeV scale”!



pseudoscalar
and
scalar
axion-like particles

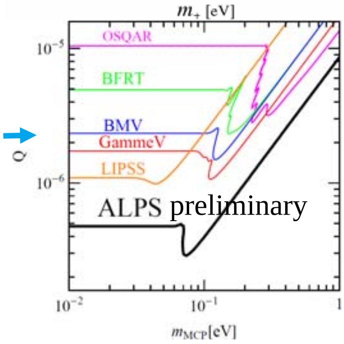






hidden sector photons
and
minicharged particles

Filling a gap remaining
from astrophysics and
other experiments!

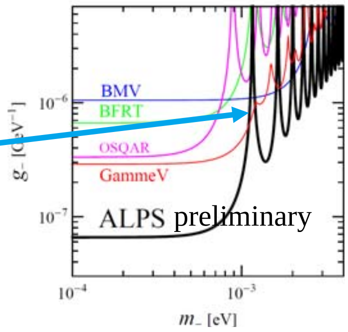


A new Method to extend the Mass Range

> The coherent phenomena probed at ALPS induce regions of insensitivity.

$$P = \left(\frac{g^2}{4} B^2 L^2 \frac{\sin^2(qL/2)}{(qL/2)^2} \right)^2$$

with $q = p_\gamma - p_\Phi$, L = *length of B field*



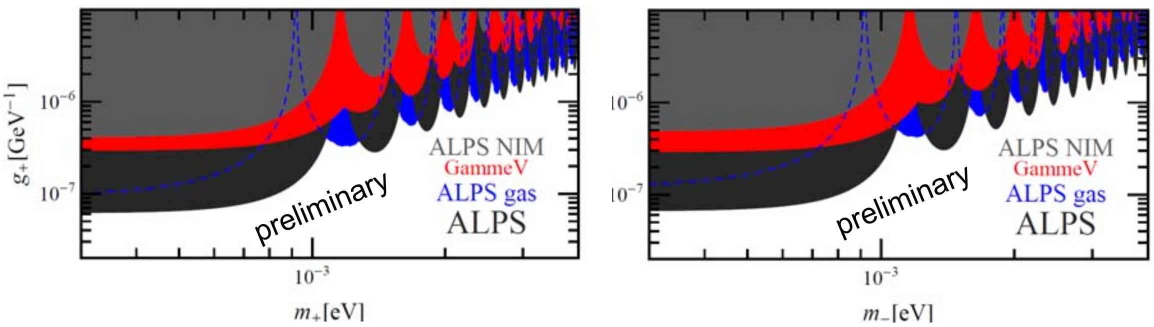
> They originate from $q \cdot L = (p_\gamma - p_\Phi) \cdot L = 2m \cdot \pi$

> Idea: change photon momentum p_γ by a small amount of gas: $p_{\gamma\,(gas)} = p_\gamma \cdot \sqrt{1+2(n-1)}$, *where n denotes the refraction index.*

> We apply this approach by taking data with a pressure of 0.18 mb of Argon in the laser and detector beam tubes.

Preliminary Results for the Argon Data

> Gaps in sensitivity for axion-like particles are closed!



> The same is done for hidden sector photon searches (about 0.11mb and 0.14mb in laser and detector tubes).

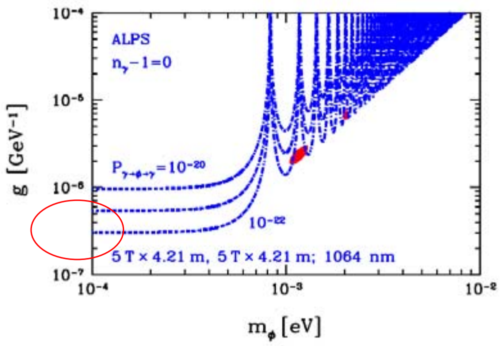
ALPS Summary

> Since spring 2009 the apparatus was improved considerably:

- Primary laser power: factor of 5
- Power built-up in resonator: factor of 15
- Detector sensitivity factor of 20

> ALPS is now in the forefront of lab experiments searching for WISPs.

- Aims as given in the LoI DESY 07-014, hep-ex/0702023 surpassed:



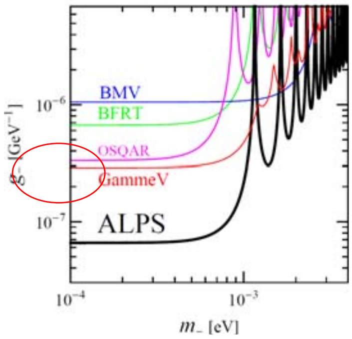


Table of Contents

Outlook

> The world-wide activities in this research field are strengthening.

Laser Experiments: History & Presence

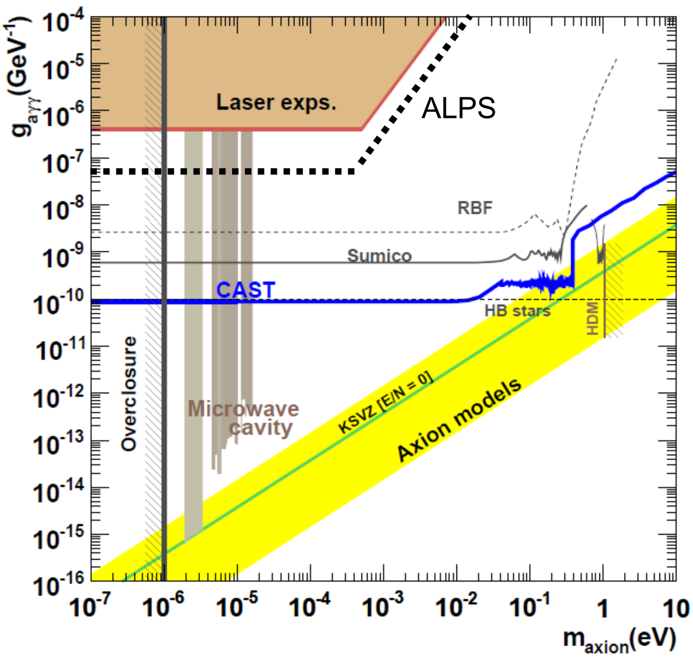
Experiment	Reference	$\Delta\theta$	ψ	LSW
ALPS (DESY/D) "Axion-Like Particle Search"	arXiv:0905.4159	✘	✘	✔
BFRT (BNL-Fermilab-Rochester-Trieste)	Phys.Rev.**D47**(1993)	✔	✔	✔
BMV (LULI/F) "Biréfringence Magnétique du Vide"	Phys.Rev.Lett.**99** (2007) Phys.Rev.**D78** (2009)	✘	✘	✔
GammeV (Fermilab/USA) "Gamma to meV particle search"	Phys.Rev.Lett.**100** (2008) Phys.Rev.Lett.**102** (2009)	✘	✘	✔
LIPSS (Jefferson Lab/USA) "LIght Pseudoscalar or Scalar particle Search"	Phys.Rev.Lett.**101** (2008) arXiv:0810.4189	✘	✘	✔
OSQAR (CERN/CH) "Optical Search for QED vacuum magnetic birefringence, Axions and photon Regeneration"	Phys.Rev.**D78** (2008)	✘	✘	✔
PVLAS (INFN/I) "Polarizzazione del Vuoto con LASer"	Phys.Rev.Lett.**96** (2006) Erratum-ibid.**99** (2007) Phys.Rev.**D77** (2008)	✔	✔	(✔)
Q&A (Hsinchu/Taiwan) "QED & Axion"	Mod.Phys.**A22** (2007)	✔	✘	✘

Markus Ahlers July 13, 2009 | Introduction | Axions | ALPs | WISPs | Summary

M. Ahlers, presentation at the 5th Patras Workshop on Axions, WIMPs and WISPs, 2009

Outlook

> The world-wide activities in this research field are strengthening, but there is still a way to go!



Axion Searches with Helioscopes and astrophysical signatures for axion(-like) particles, K. Zioutas et al., New J. Phys. 11 (2009) 105020

Outlook

> The world-wide activities in this research field are strengthening, but there is still a way to go!

> Experience gathered with ALPS is a firm foundations for continuing to probe the hints for WISPs, now on larger scales.

> The essential strength of ALPS is the collaboration of particle physicists (theory and experiment) and laser physicists from the gravitational wave detector community.

> The ALPS collaboration is drafting a plan for a possible ALPS-extension to be decided on in summer 2010.

> However, is this worthwhile to do?

YES, indeed!

Hints for ALP Physics?

Remind:

> A QCD axion in the mass region of 10^{-5} to 10^{-4} eV would be a “perfect” cold Dark Matter candidate.

Astrophysics:

> *Axions and the cooling of white dwarf stars.*
J. Isern et al., arXiv:0806.2807v2 [astro-ph], Astrophys.J.L. 682 (2008) L109

> *Evidence for a New Light Boson from Cosmological Gamma-Ray Propagation?* M. Roncadelli et al., arXiv:0902.0895v1 [astro-ph.CO]

> *AGN X/γ-ray luminosity relations: hints for axion-like particles*
C. Burrage et al., arXiv:0902.2320v1 [astro-ph.CO], Phys.Rev.Lett.102:201101,2009

> Does the X-ray spectrum of the sun points at a 10 meV axion?
K. Zioutas et al., arXiv:0903.1807v4 [astro-ph.SR]

> Large-Scale Alignments of Quasar Polarization Vectors: Evidence at Cosmological Scales for Very Light Pseudoscalar Particles Mixing with Photons? D. Hutsemekers et al., arXiv:0809.3088v1 [astro-ph]

Large-Scale Alignments of Quasar Polarization Vectors

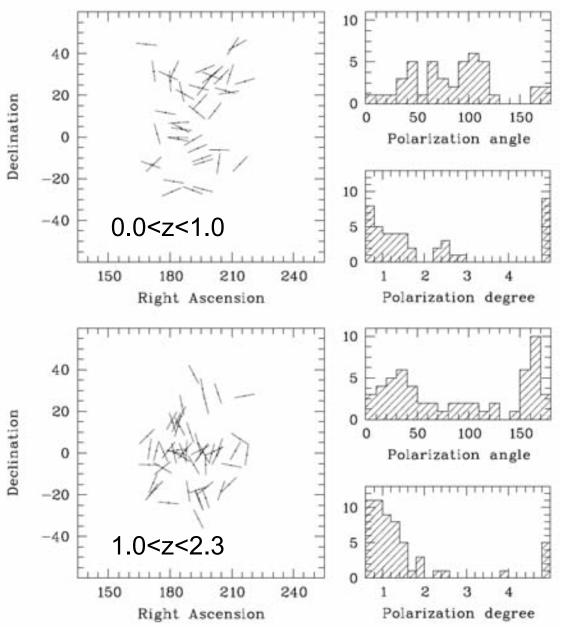
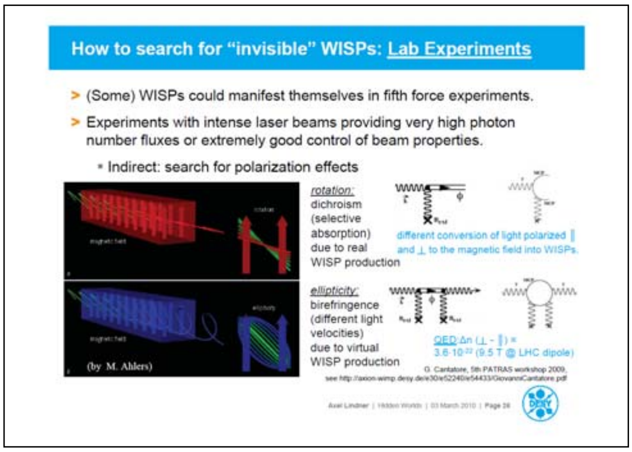


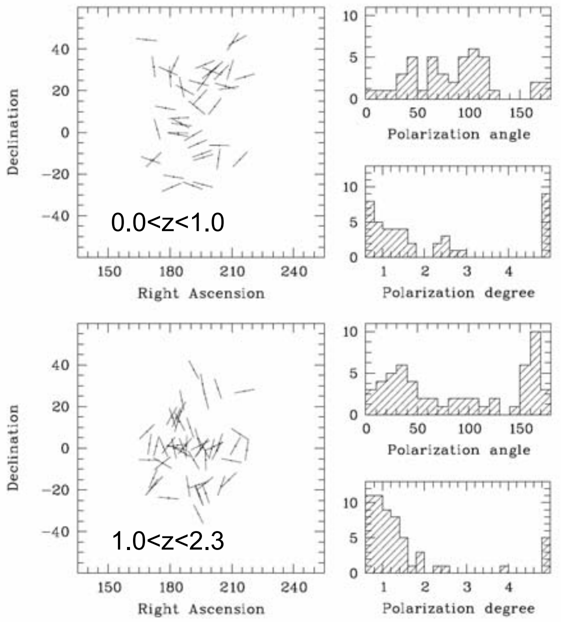
Figure 1. Maps of quasar polarization vectors towards the North Galactic Pole region, together with the corresponding distributions of polarization angle (in °) and polarization degree (in %). The regions illustrated are delimited in right ascension and declination by $168° \leq \alpha \leq 218°$ and $\delta \leq 50°$, and in redshift by $0.0 \leq z < 1.0$ (top, 43 objects) and $1.0 \leq z \leq 2.3$ (bottom, 56 objects). At low (resp. high) redshifts the probability that the distribution of polarization angles is drawn from an uniform distribution is 0.3% (resp. 0.2%) with a mean value of the polarization angles around 79° (resp. 8°).

D. Hutsemekers et al., arXiv:0809.3088v1 [astro-ph]

> Quasar polarization vectors appear aligned over 1 Gpc regions at low and high redshifts.



Large-Scale Alignments of Quasar Polarization Vectors



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D. Hutsemekers et al., arXiv:0809.3088v1 [astro-ph]

> Quasar polarization vectors appear aligned over 1 Gpc regions at low and high redshifts.

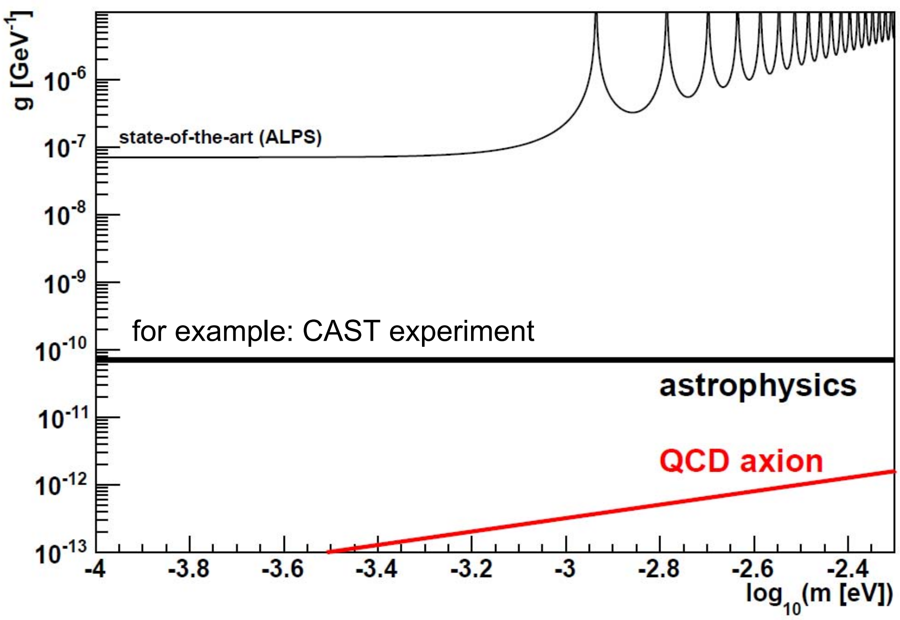
> Photon-ALP oscillation in cosmological magnetic fields might explain this effect.

> Parameters:

- Magnetic field:
  L ≅ 10 Mpc, B ≅ 0.1 μG
- Axion-Like-Particle:
  m ≅ 10^{-14} eV,
  g ≅ $5 \cdot 10^{-12}$ 1/GeV *(only g·B is relevant)*

A possible Scenario for ALPS II

> Still a way to go!

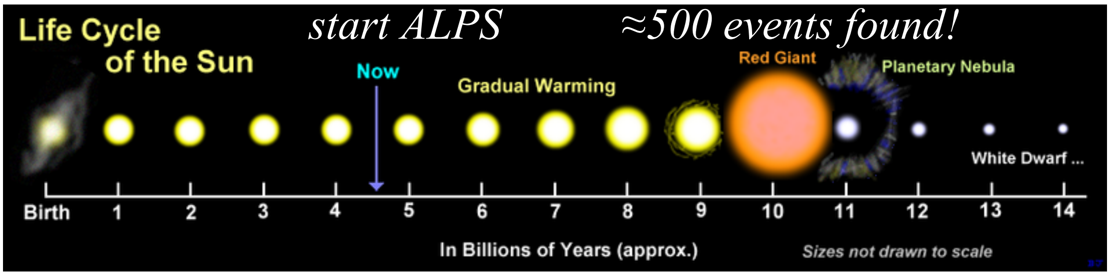


More Beam Time for Lab Experiments?

CAST: expected ALPs flux from the sun for $g=10^{-10}$ GeV^{-1}:
$\Phi_a = g^2_{10} \cdot 3.75 \cdot 10^{11}$ 1/cm²/s = $1.5 \cdot 10^{12}$ s^{-1}

ALPS: expected ALPs flux for $g=10^{-10}$ GeV^{-1}: $\Phi_a = 3 \cdot 10^3$ s^{-1}

Nine orders of magnitude are difficult to beat just by beam time:
(the ALPs have to convert into photons for detection: $\sim g^4$)



Need a more clever approach!

A possible Scenario for ALPS II

Basics:

> Need to switch to a scenario with at least two magnets in order to have a handle on both mirrors defining the resonator.
At ALPS there is no access and no firm support of the mirror in the middle of the HERA dipole.

> Ensure clean room conditions from the beginning.
At ALPS this was introduced at a late stage.

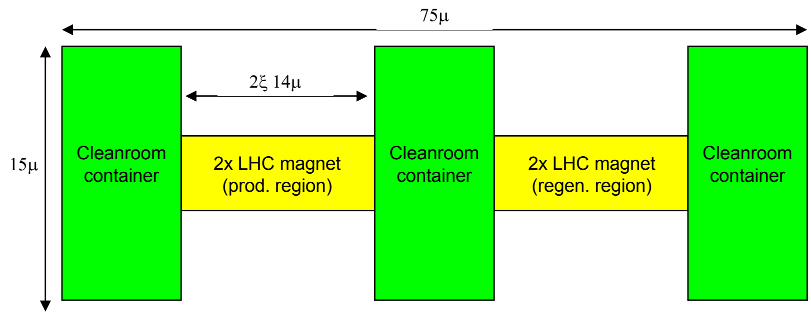
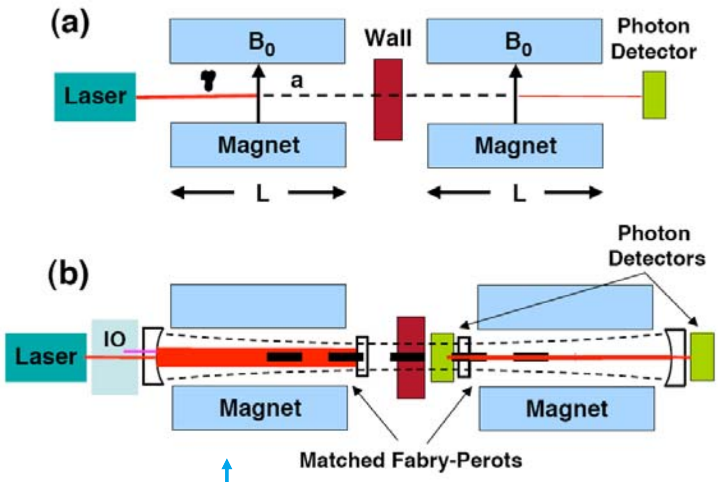


Fig. 1: ALPS II - setup of LHC magnets and cleanroom containers within hall 55. The magnets need cryogenic infrastructure. The cleanroom containers will host all optics, electronics and working areas.

A possible Scenario for ALPS II

Essential:

> Implementation of a second cavity in the regeneration part of the experiment to enhance the conversion probability WISP→ photon.



Realized at ALPS

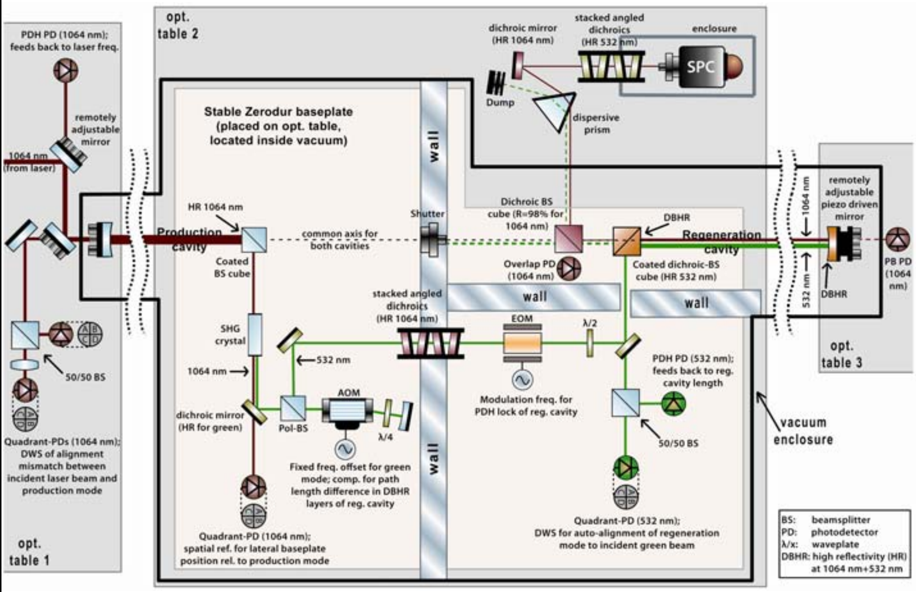
"Resonantly enhanced Axion-Photon Regeneration"
[P. Sikivie](), [D.B. Tanner]() , [Karl van Bibber](). *Phys.Rev.Lett.98:172002,2007.*

(also [F. Hoogeveen](), [T. Ziegenhagen](), DESY-90-165, Nucl.Phys.B358)

A possible Scenario for ALPS II

Laser and resonators:

150 kW effective laser power, second cavity with a finesse of more than 10^5.



T. Meier (AEI Hannover):

Challenging, but not a daydream.

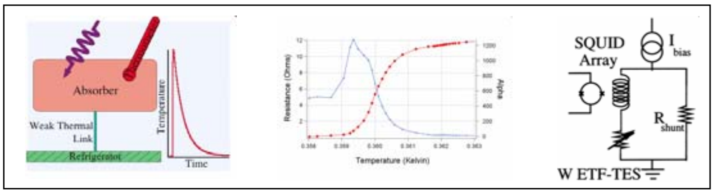
Based on existing technologies for LIGO and LISA.

Alternative in the US:
G. Mueller, P. Sikivie, D. B. Tanner, K. v.Bibber
[10.1103/PhysRevD.80.072004]()

A possible Scenario for ALPS II

Detectors:

> Strive for a “background-free” single photon counter: Transition Edge Sensor @ 100 mK?



> Heterodyne detection: mix two signals and search for a Fourier component?

$$S = |E_{SO}e^{i(\omega_1 t+\phi)} + E_{LO}e^{i\omega_2 t}|^2$$
$$= E_{LO}^2 + 2E_{LO}E_{SO}\cos(\Omega t + \phi)$$

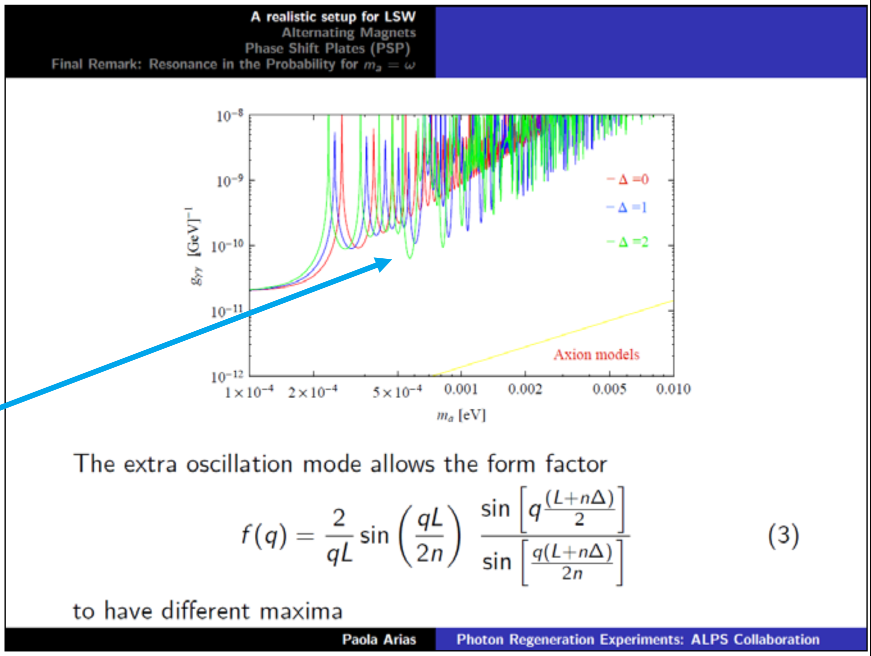
A possible Scenario for ALPS II

Detailed studies have started:

For example:

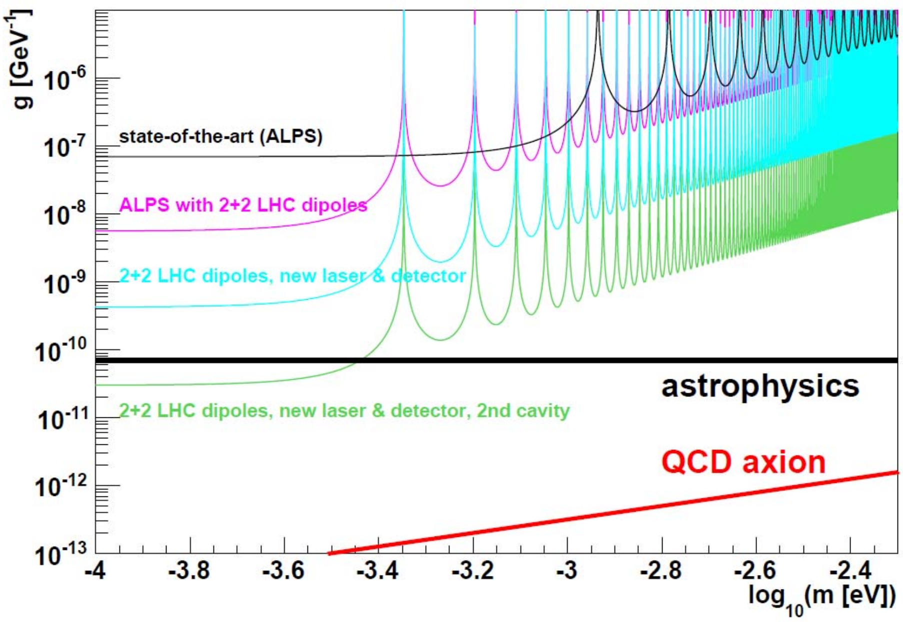
the world’s first study of realistic magnet configurations by P. Arias (DESY).

Increase sensitivity for certain masses!



A possible Scenario for ALPS II

> Possible sensitivity in 2015 / 2016:



A possible Scenario for ALPS II

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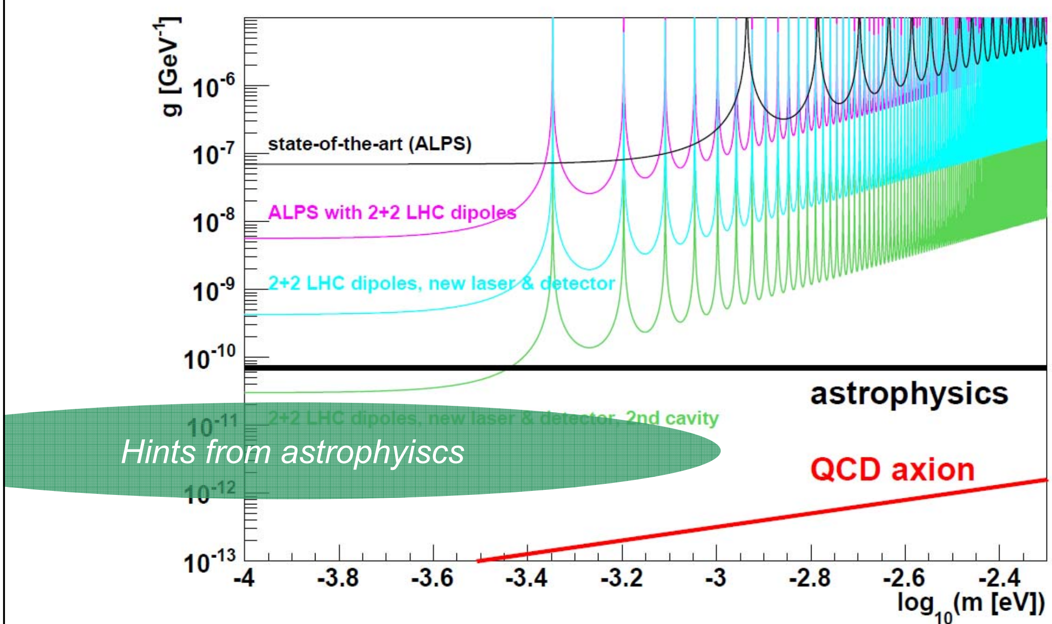
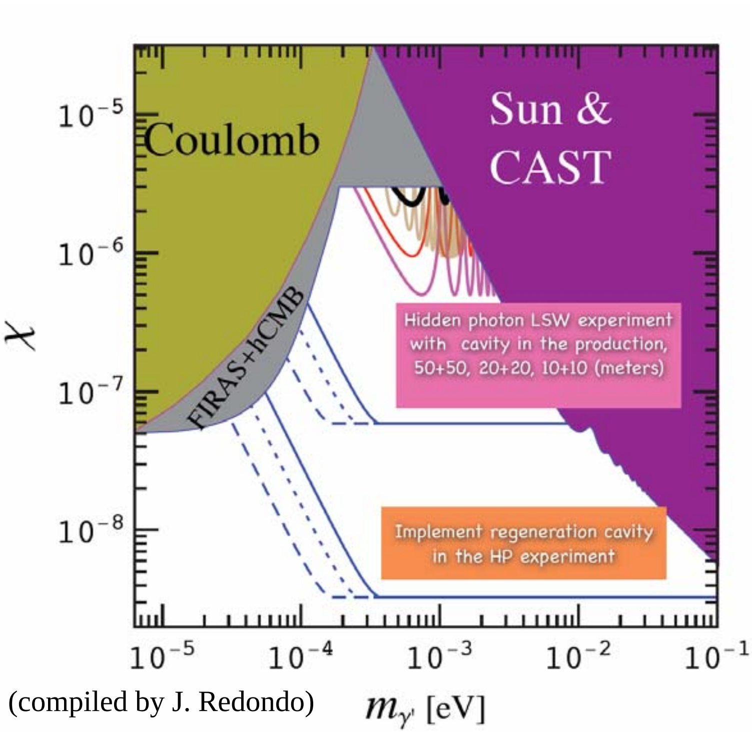
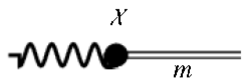


Without Magnets: Searching for hidden Photons



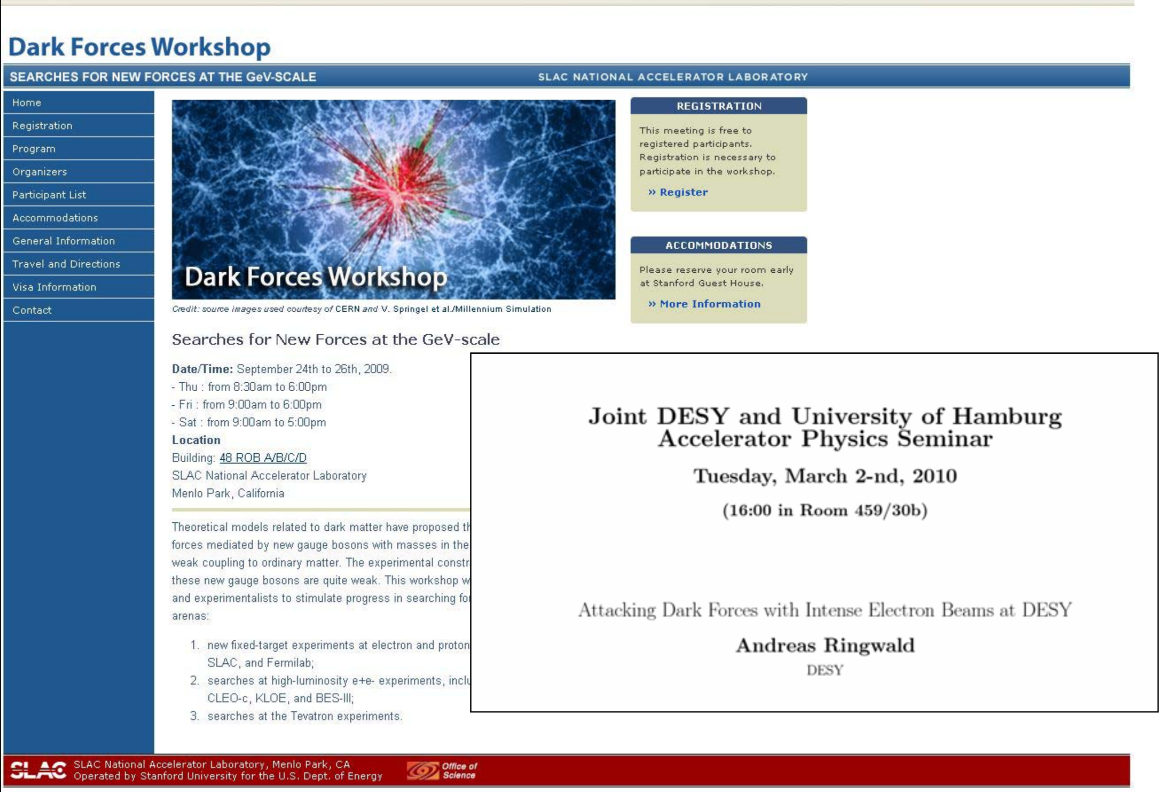


Only laboratory experiments searching for massive hidden sector photons might close the gap in the meV mass region!
Same laser and detector technology, but no magnets needed.
Only long straight vacuum tubes!

International Activities: Annual Workshops

> Please contact A. Ringwald or me if you want to contribute to PATRAS 2010 (5 to 9 July) in Zürich, Switzerland.

Another rediscovered Area: GeV Dark Forces



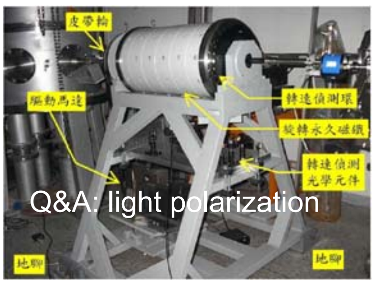
http://www-conf.slac.stanford.edu/darkforces2009/

Summary

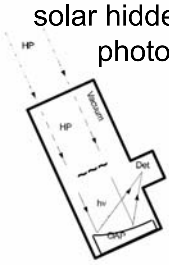
> There are some fascinating leftovers from main stream particle physics
- WISP physics, GeV dark forces

which may hide solutions to long-standing and fundamental physics question
- CP conservation in QCD, dark matter, (dark energy), astrophysics miracles

> Efforts to explore the leftovers are very moderate.



SHIPS:
DESY / Uni HH
proposal for
solar hidden
photons



> **We should close these gaps of knowledge!**

Thanks to the ALPS Collaboration!

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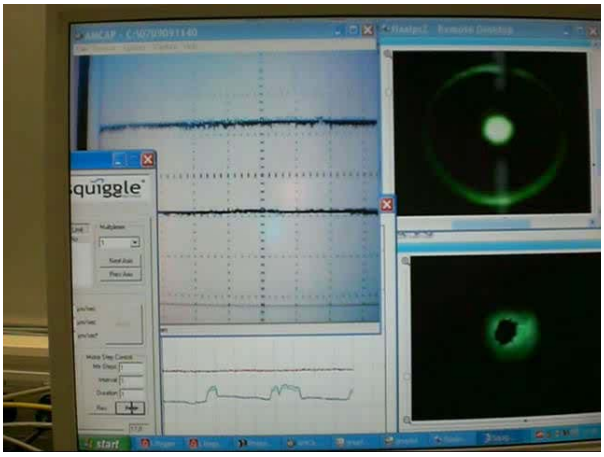
Intensity of light inside the ALPS magnet

Intensity of light in the frequency doubling resonator



Scattered light from coupling mirror (resonator lock))

Reference beam (pointing stability)