Illuminating hidden Worlds

Particle Physics at lowest Energies

with the ALPS Experiment

A. Lindner, DESY

Seminar DESY in Zeuthen,
6 January 2010

HELMHOLTZ
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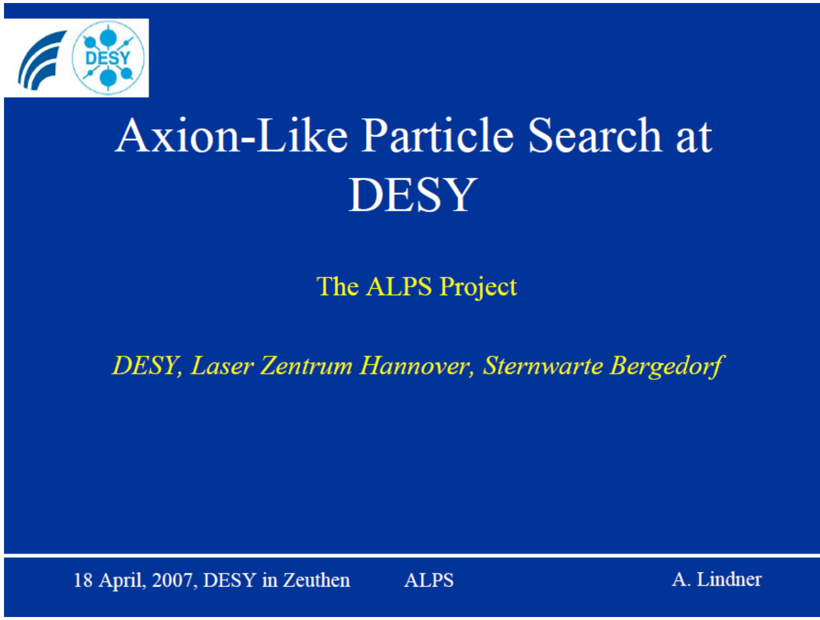
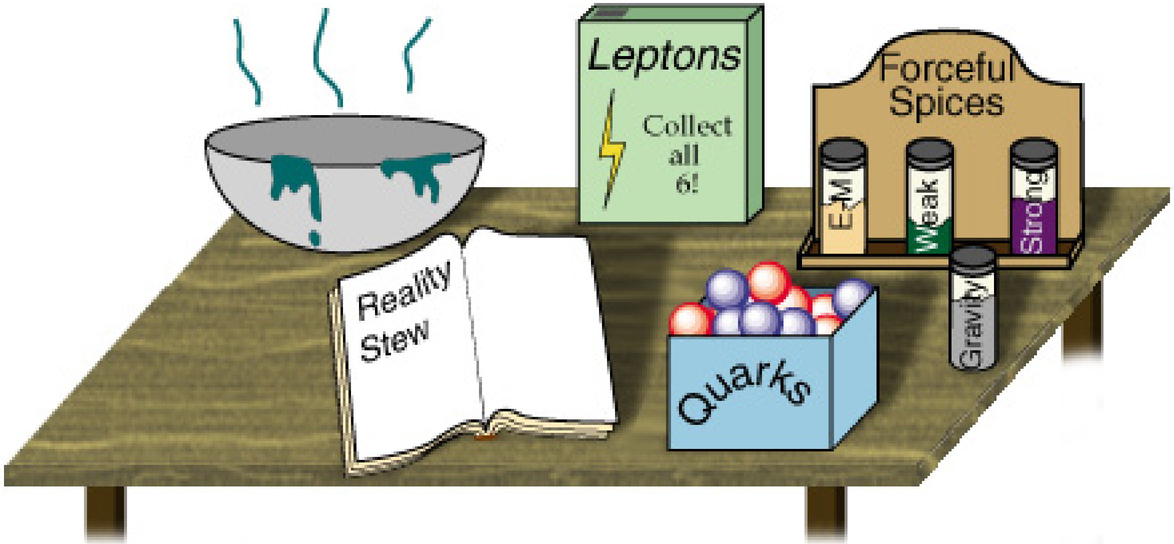
Seminar DESY in Zeuthen, 18 April 2007:



What is it all about?

We are striving for the recipe of our world:



What are the ingredients necessary to explain all and every phenomena?

at least in principle …

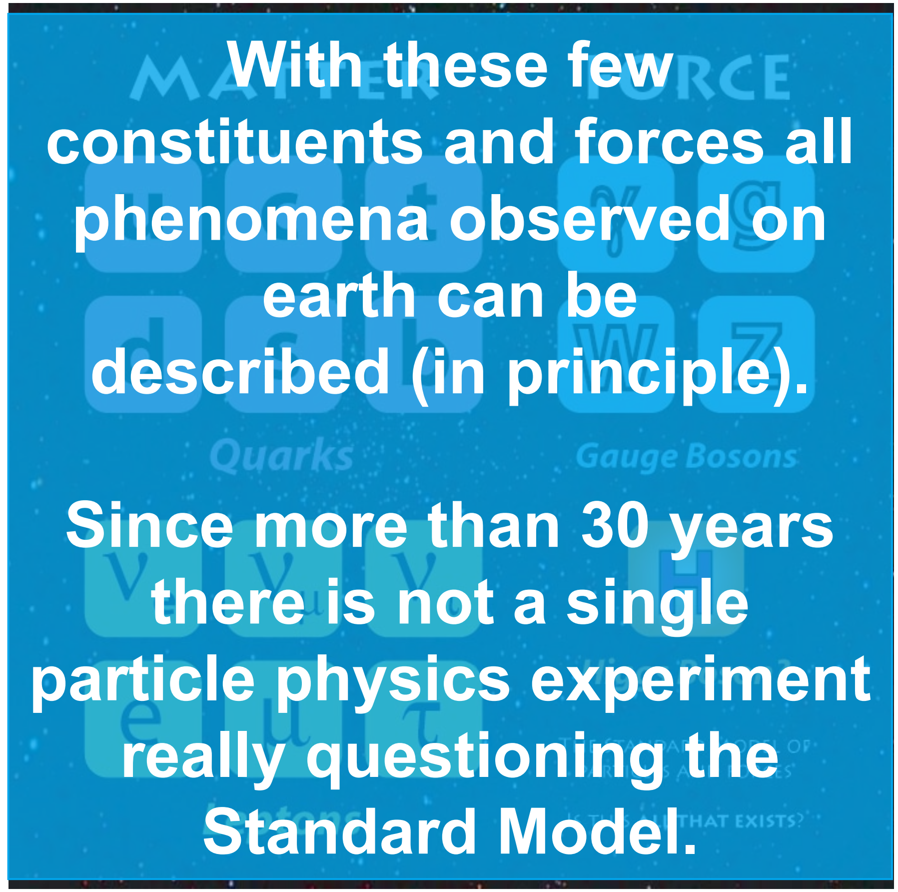
The Standard Model of Constituents and Forces

<u>Constituents:</u>

- Quarks
- Leptons

<u>Forces:</u>

- electromagnetic
- strong
- weak



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.

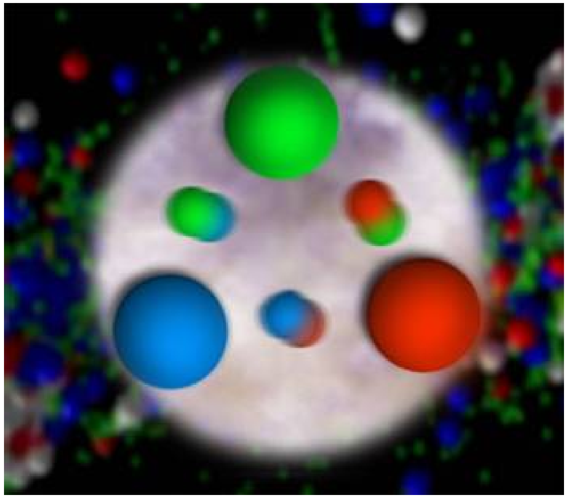
http://www.gridpp.ac.uk/cubes/

Only the Higgs boson is missing!

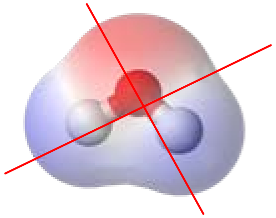
A Flaw in the Standard Model?

The neutron has a strange property:

It consists of three charged quarks, but does not show any 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?

However, the neutron has a magnetic moment of

$$-1.913043\ \mu_N$$

related to the spin of the neutron.

JANUARY 15, 1940 PHYSICAL REVIEW VOLUME 57

A Quantitative Determination of the Neutron Moment in Absolute Nuclear Magnetons

LUIS W. ALVAREZ, *Radiation Laboratory, Department of Physics, University of California, Berkeley, California*

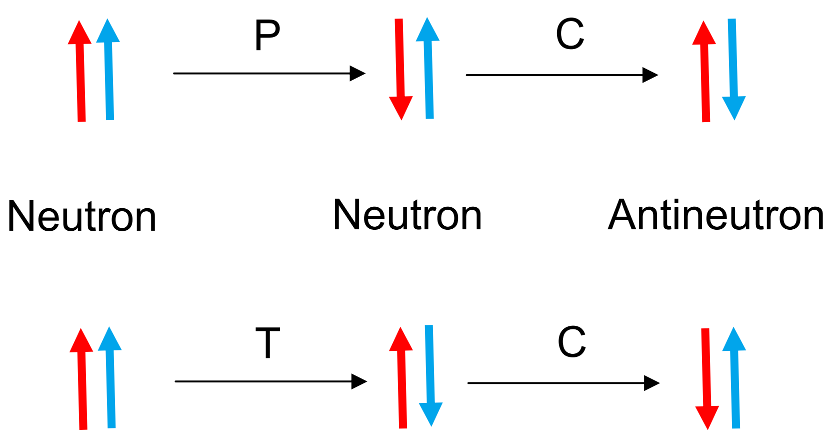
AND

F. BLOCH, *Department of Physics, Stanford University, Palo Alto, California*

(Received October 30, 1939)

… The fact alone that μ_p differs from unity and μ_n differs from zero indicates that, unlike the electron, these particles are not sufficiently described by the relativistic wave equation of *Dirac* and that other causes underly their magnetic properties.

The Neutron's EDM and CP Conservation



If the neutron has an electric dipole moment in addition to the magnetic dipole moment, C·P (or C·T) is not a valid symmetry
(both moments change from parallelism to anti-parallelism or vice versa).

The strong interaction conserves CP $\leftrightarrow$ no neutron electric dipole moment
(a magnetic dipole moment is measured!)

A Flaw in the Standard Model?

However, C·P conservation is *not* an intrinsic feature of the theory of strong interactions (QCD) with massive fermions (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?

Detour: C·P is not only an academic Question

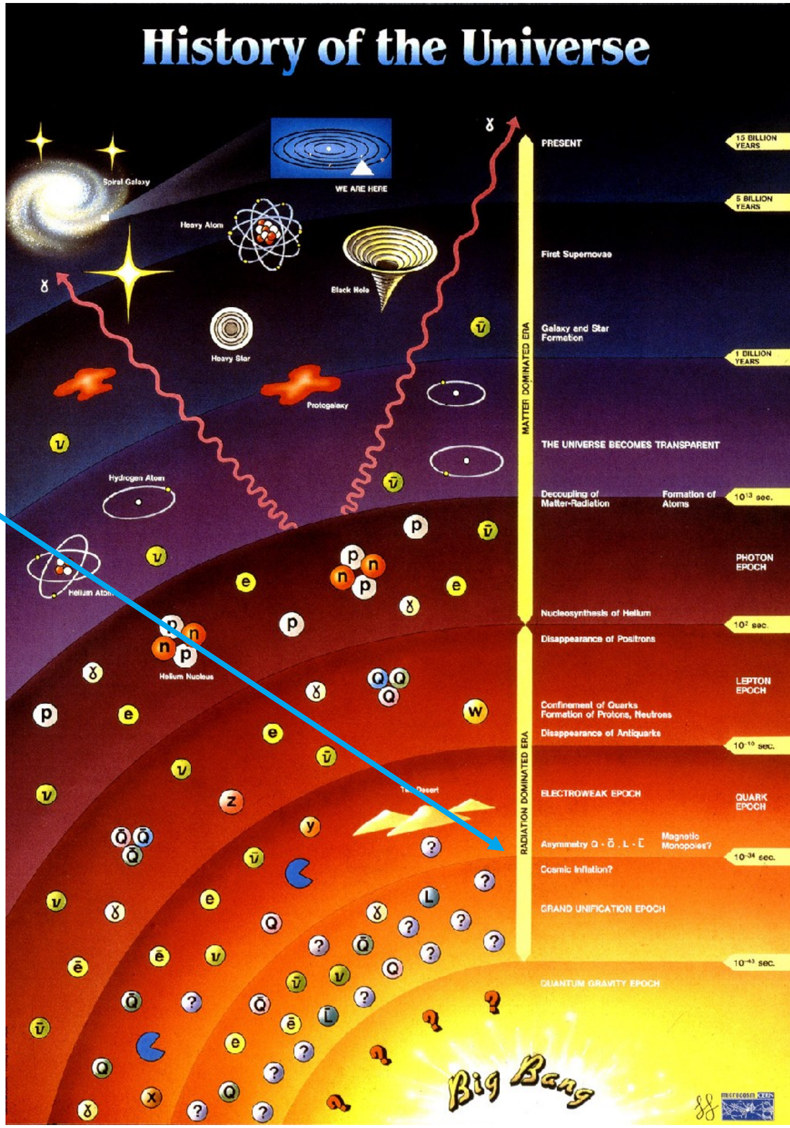
We need an interaction with C·P violation to explain why we observe only matter and not (an equal amount) of antimatter in the universe.

Why did matter and antimatter not annihilate completely about 10^{-34}s after the Big Bang?

C·P violation is essential to explain our existence!

The C·P violation of the weak interaction is much too weak for an explanation.

QCD could do the job in principle, but experiments show that QCD conserves C·P!



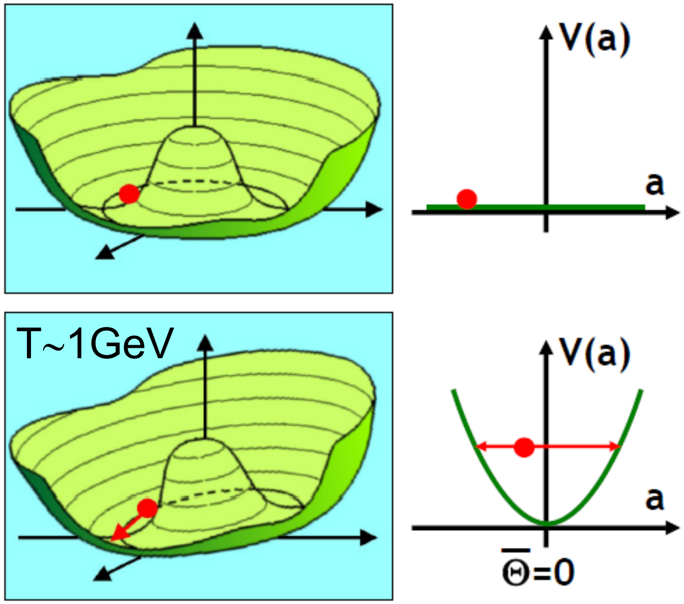
From a Flaw to a new Particle

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!

<u>Peccei-Quinn 1977:</u>
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

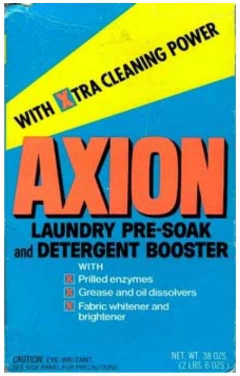
Wilczek and Weinberg independently noticed 1978:

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

<u>Summary:</u>

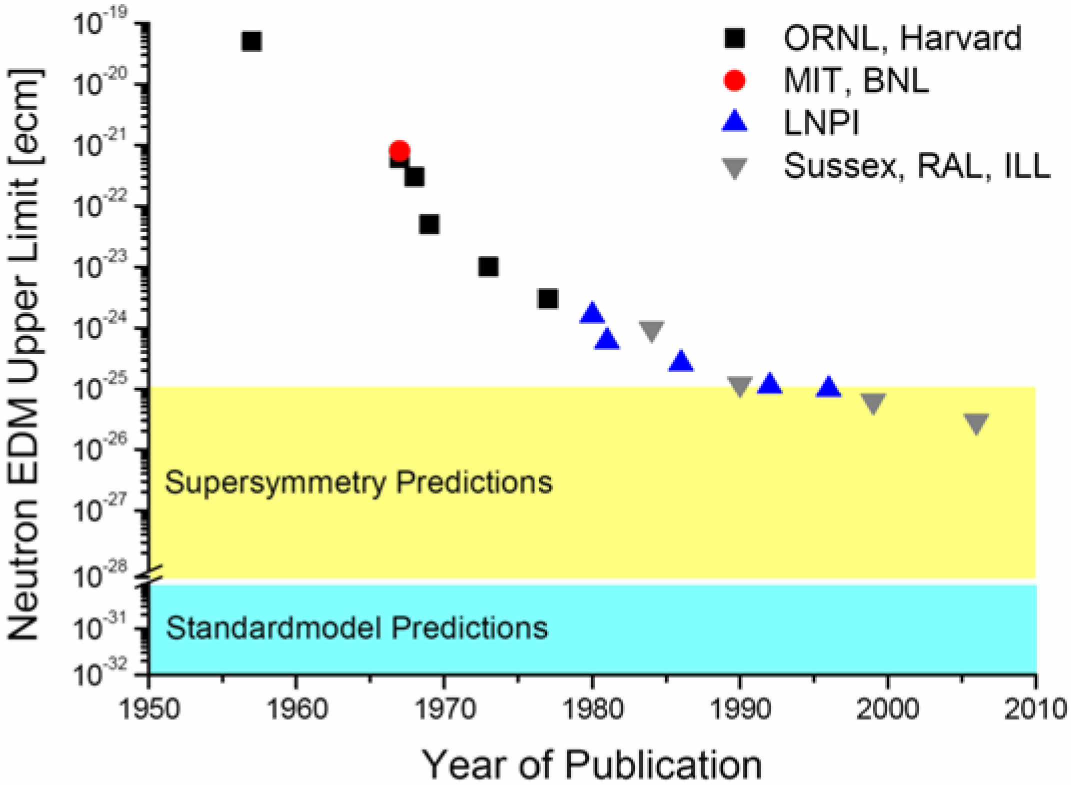
One can explain the C·P conservation in QCD if a new particle, the axion, exists.

The axion “cleans” QCD.



The Neutron's EDM: a Window to "new" Physics

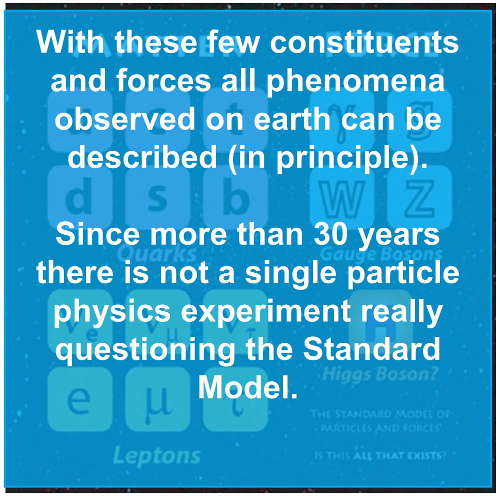
Experimental limits on the neutron EDM start to probe predictions by supersymmetry.



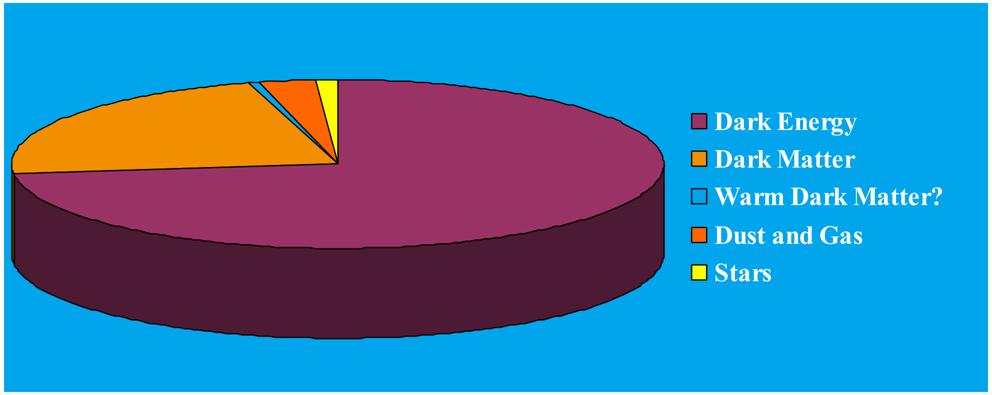
http://en.wikipedia.org/wiki/Neutron_electric_dipole_moment

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!

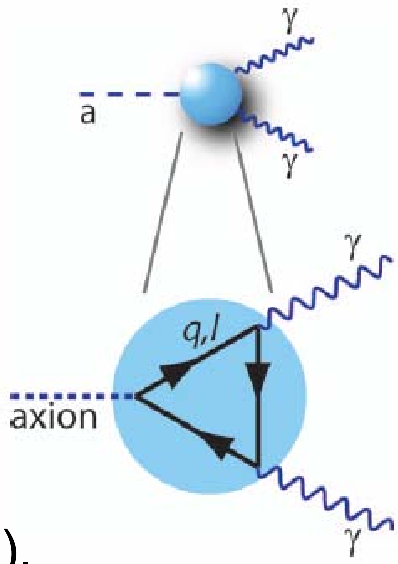
Properties of the QCD Axion

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

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

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^{9}GeV < 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.

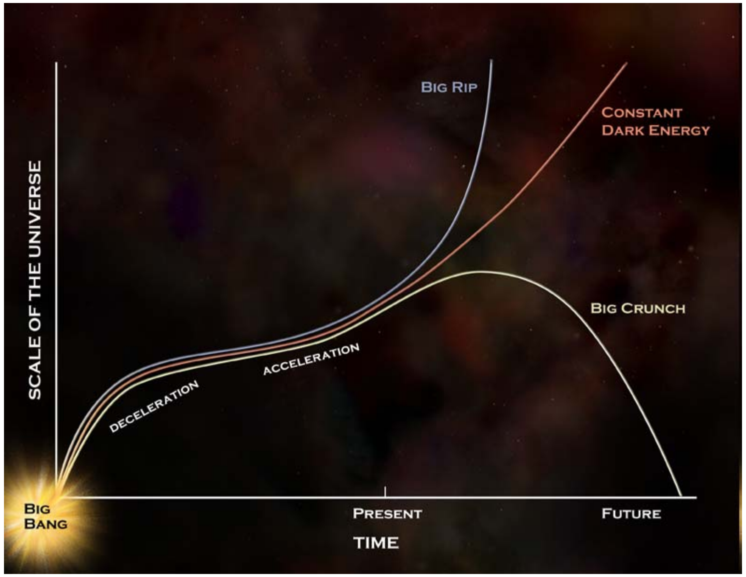
Another special Interest in the meV Energy Scale

The density of Dark Energy in our Universe is

10^{-29}g/cm^3, being equivalent to

$\rho_{DE} \cong (2\ \mathrm{meV})^4$.

Does this hint at new physics at the meV scale?



http://chandra.harvard.edu/photo/2004/darkenergy/future_universe.jpg

The cosmological constant problem, *S. Weinberg*, Rev. Mod. Phys. 61, 1–23 (1989)

… 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.

Unfortunately it seems to be impossible to construct a theory with one or more scalar fields having the assumed properties. This can be seen in very general terms. …

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From Axions to ALPs and WISPs

There might be much more than a QCD axion:

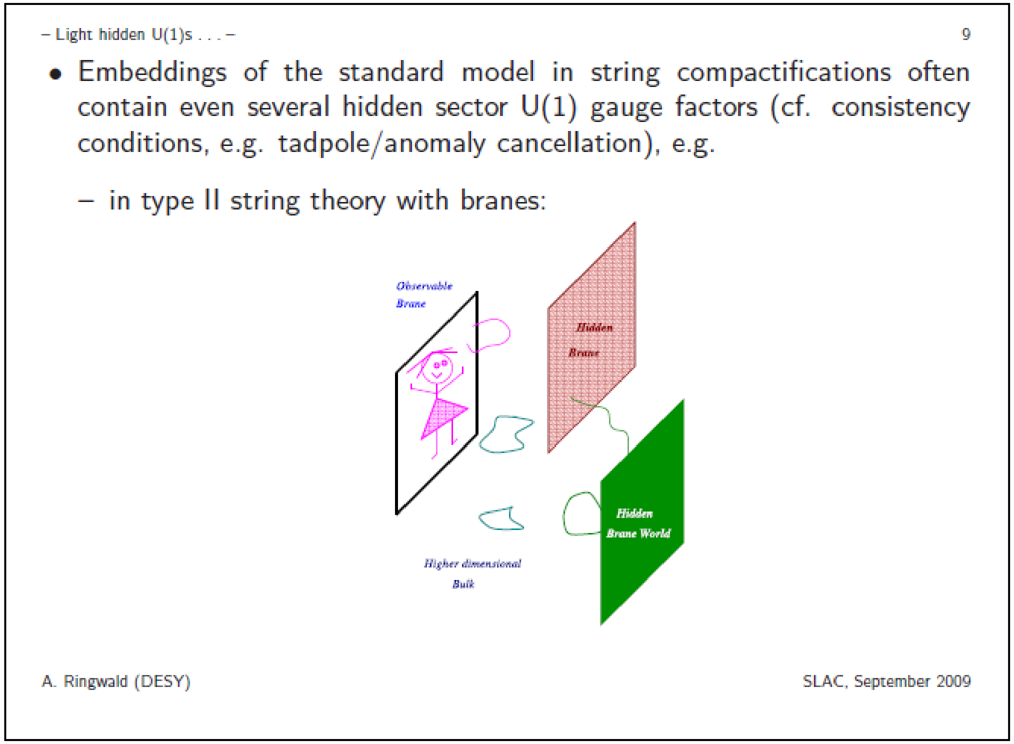
> ALPs: “axion-like particles”

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

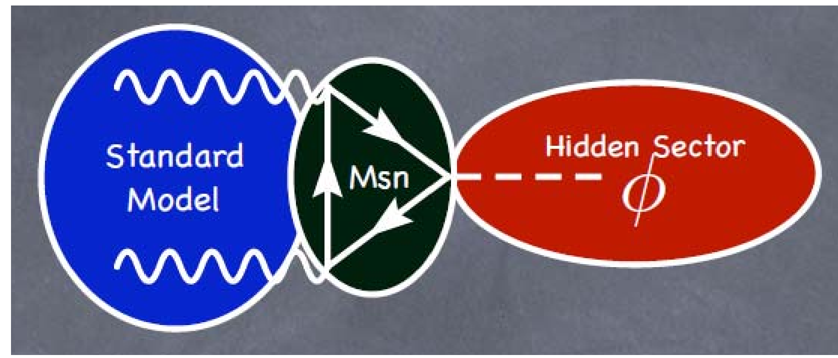
Naturally Light Hidden Photons in LARGE Volume String Compactifications
M. Goodsell, J. Jaeckel, J. Redondo and A. Ringwald,
arXiv:0909.0515 [hep-ph], JHEP 0911:027,2009
Extra “hidden" U(1) gauge factors are a generic feature of string theory that is of particular phenomenological interest. They can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

WISPs: Access to 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 also probe very high energy scales.

A Glimpse into Theory of WISPs

- Theory is starting to develop detailed predictions, which in turn will allow to limit theory parameters from experimental limits on WISP production (if indeed nothing new will be found).

- Example for hidden photons.

IPPP/09/63; DCPT/09/126; DESY 09-123

Naturally Light Hidden Photons in LARGE Volume String Compactifications

Mark Goodsell[1], Joerg Jaeckel[2], Javier Redondo[3] and Andreas Ringwald[3]

[1] *LPTHE, Université Pierre et Marie Curie - Paris VI, France*

[2] *Institute for Particle Physics and Phenomenology, Durham University, Durham DH1 3LE, United Kingdom*

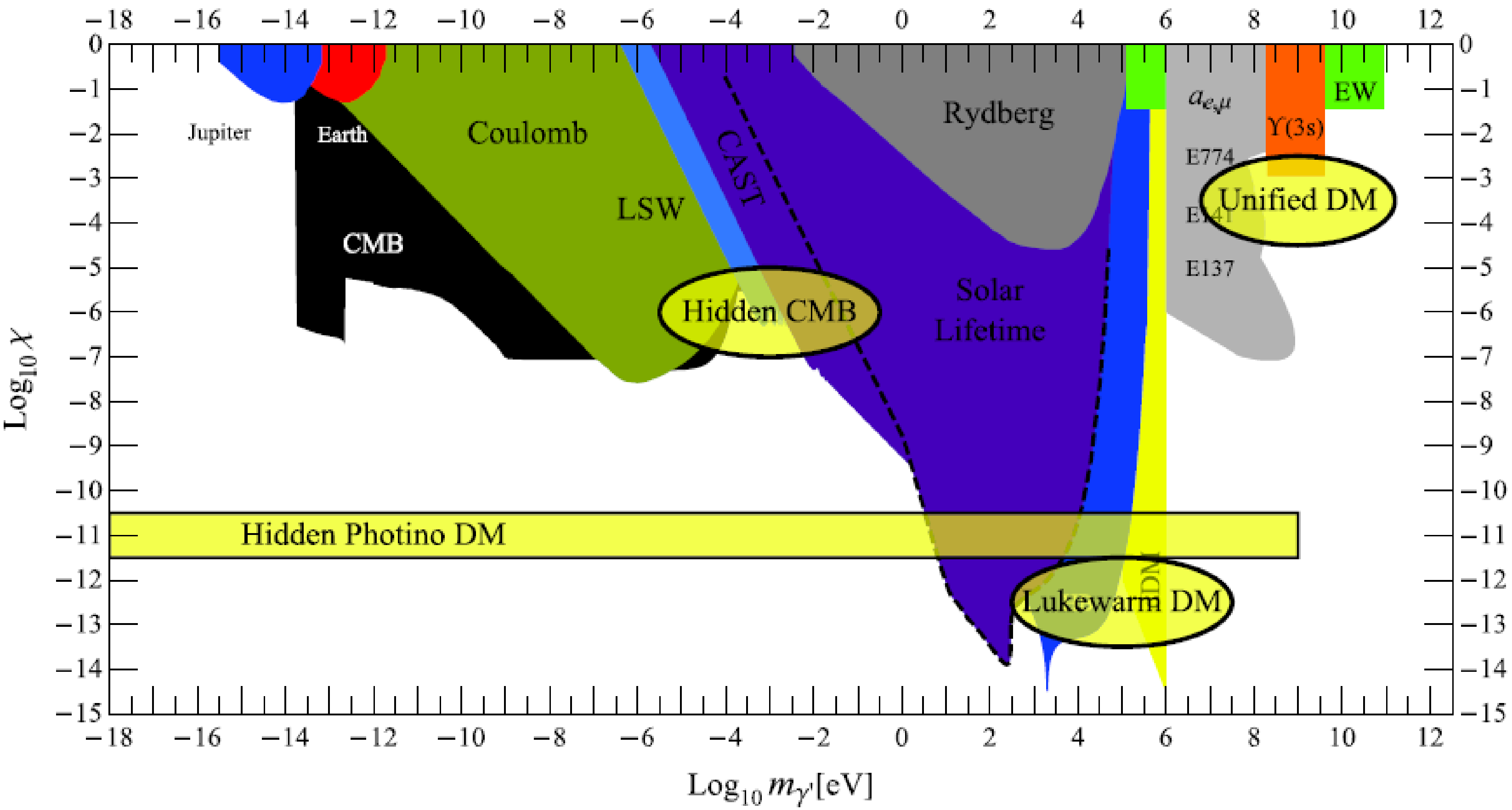
[3] *Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany*

Abstract

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. In this paper we investigate the masses and the kinetic mixing of hidden U(1)s in LARGE volume compactifications of string theory. We find that in these scenarios the hidden photons can be naturally light and that their kinetic mixing with the ordinary electromagnetic photon can be of a size interesting for near future experiments and observations.

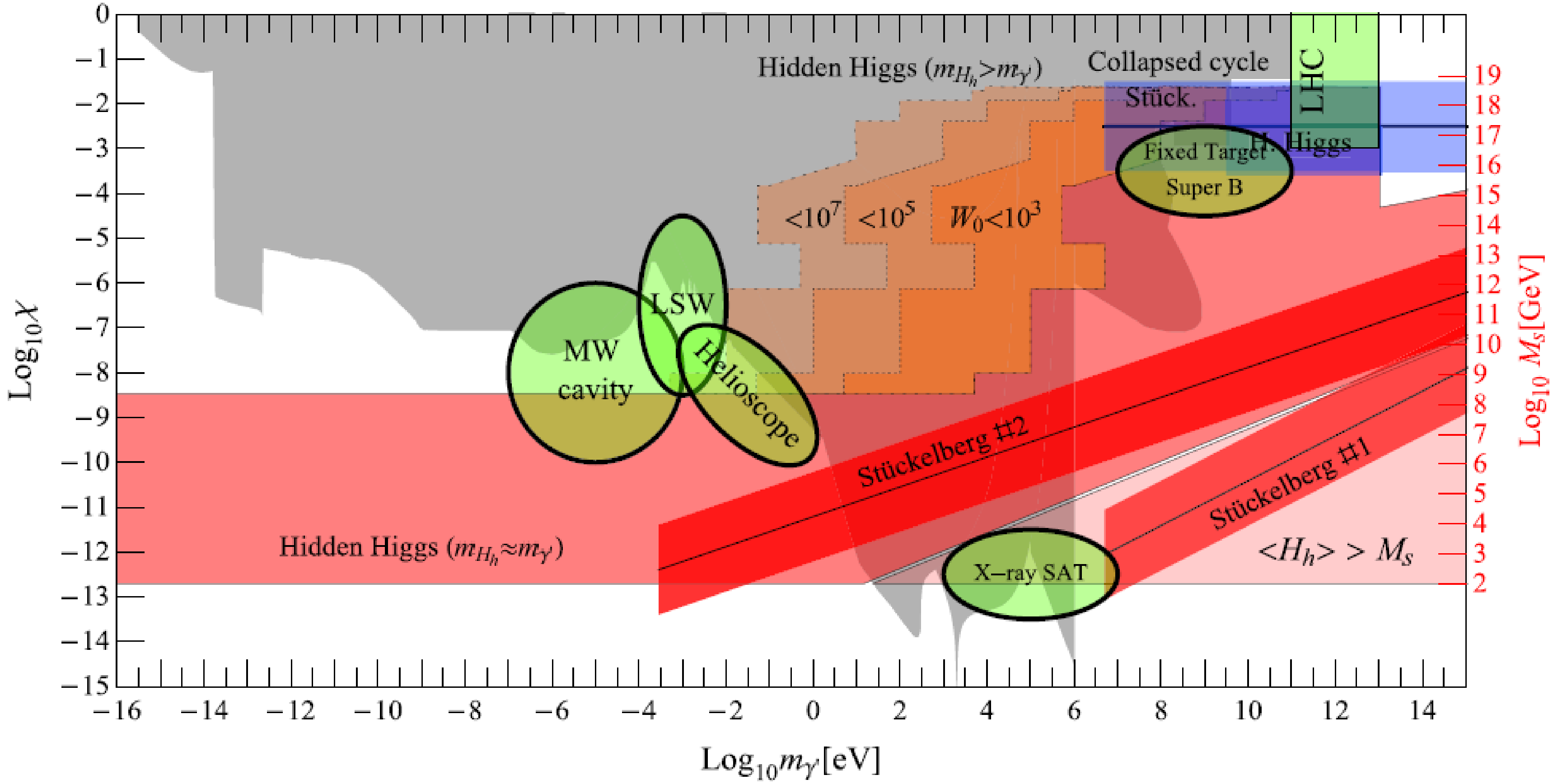
A Glimpse into Theory of WISPs

> The hidden photon scenario …



Notes on the Physics Case: Theory II

> … prognoses and experimental test.



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.

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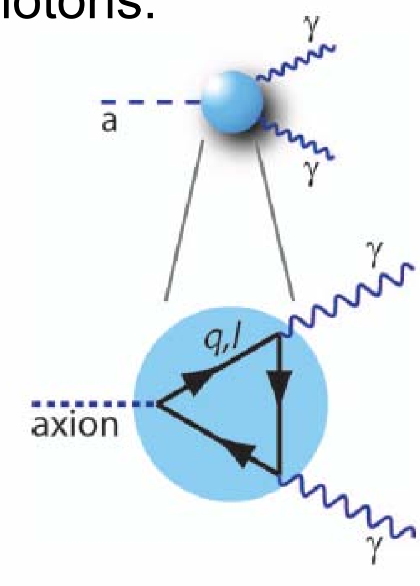
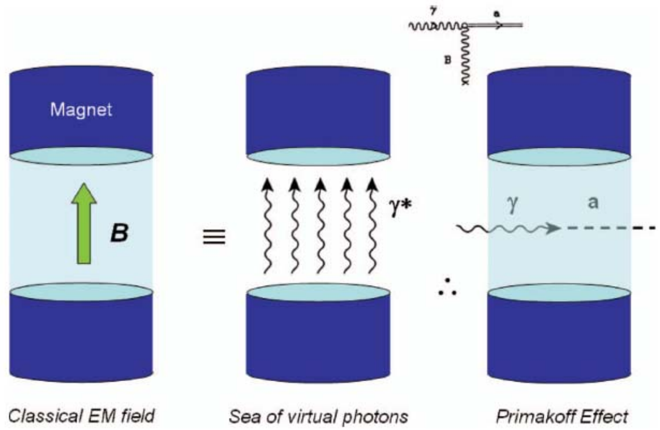
How to search for “invisible” WISPs: exemplary Basics

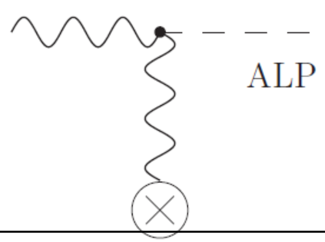
- Neutral scalar or pseudoscalar WISPs couple to two photons:



- 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

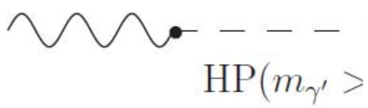


- WISPs can be produced by light shinning into a magnetic field.
- WISPs entering a magnetic field can convert into a photon.

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

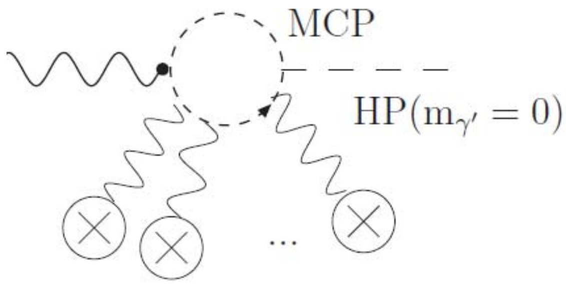
How to search for "invisible" WISPs: exemplary Basics

- 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: “loop effects”



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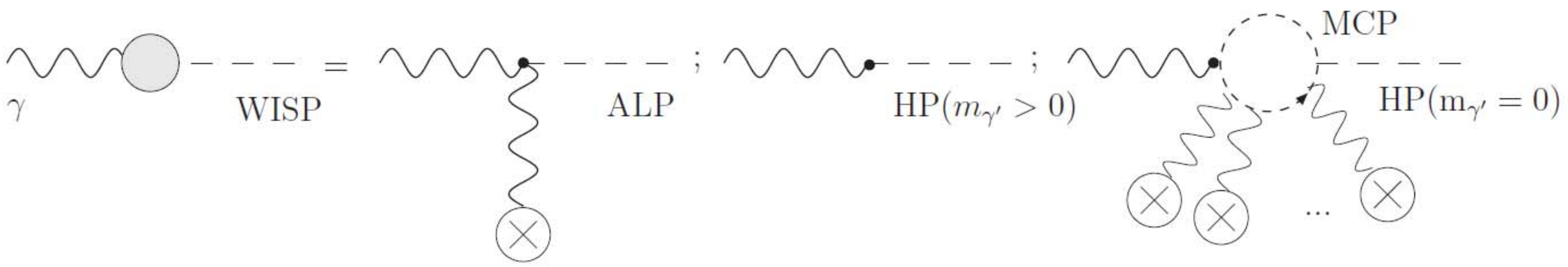
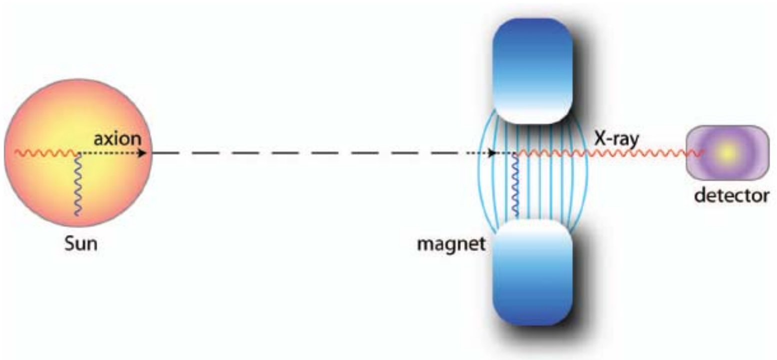


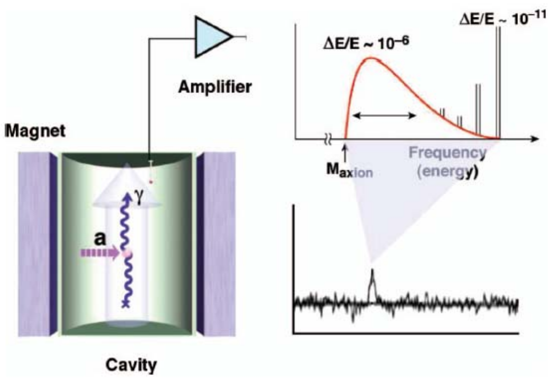
Axion-Like Particles, *Hidden Photons,* *MiniCharged Particles*

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)



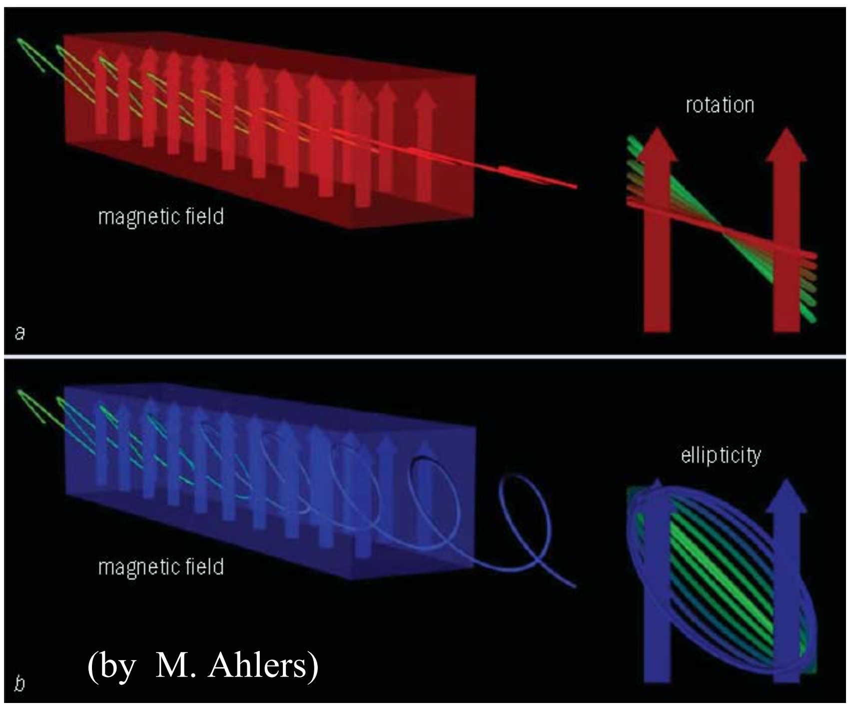
  - Search for halo dark matter axions (ADMX at Livermore)



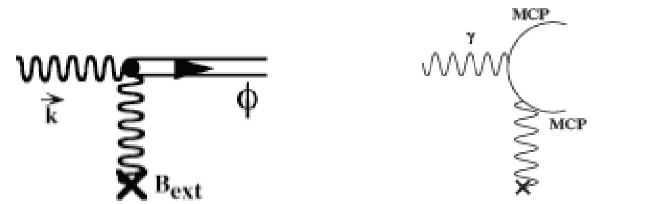
The Search for Axions, Carosi, van Bibber, Pivovaroff, Contemp. Phys. 49, No. 4, 2008

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

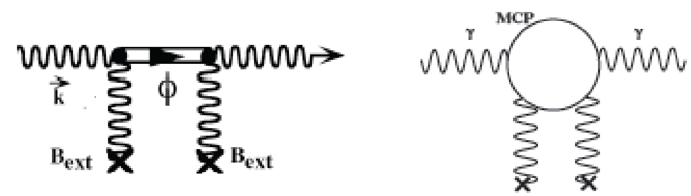


rotation: dichroism due to real WISP production



different absorption of light polarized ∥ and ⊥ to the magnetic field

ellipticity: birefringence due to virtual WISP production

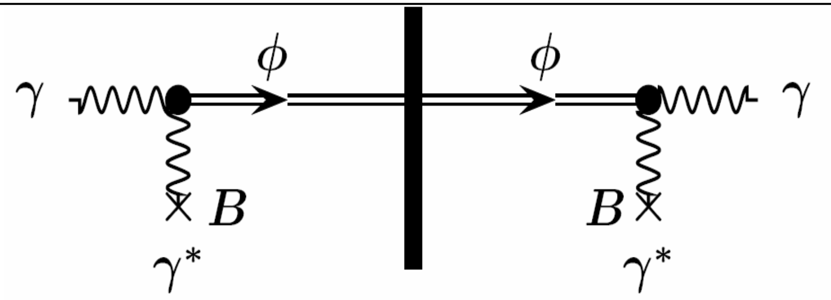


QED:Δn (⊥ - ∥) = $3.6 \cdot 10^{-22}$ (9.5 T @ LHC dipole)

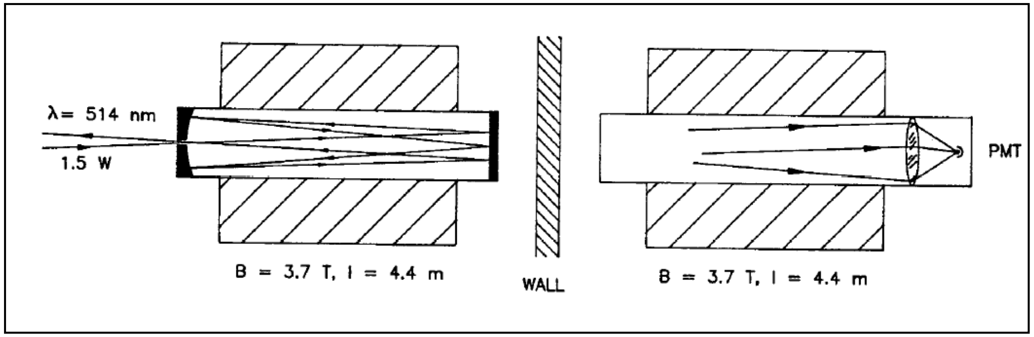
G. Cantatore, 5th PATRAS workshop 2009,
see http://axion-wimp.desy.de/e30/e52240/e54433/GiovanniCantatore.pdf

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-shinning-through-a-wall” (LSW)



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



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

A rather boring situation?!

The Return of the Axion: PVLAS 2005 / 2006

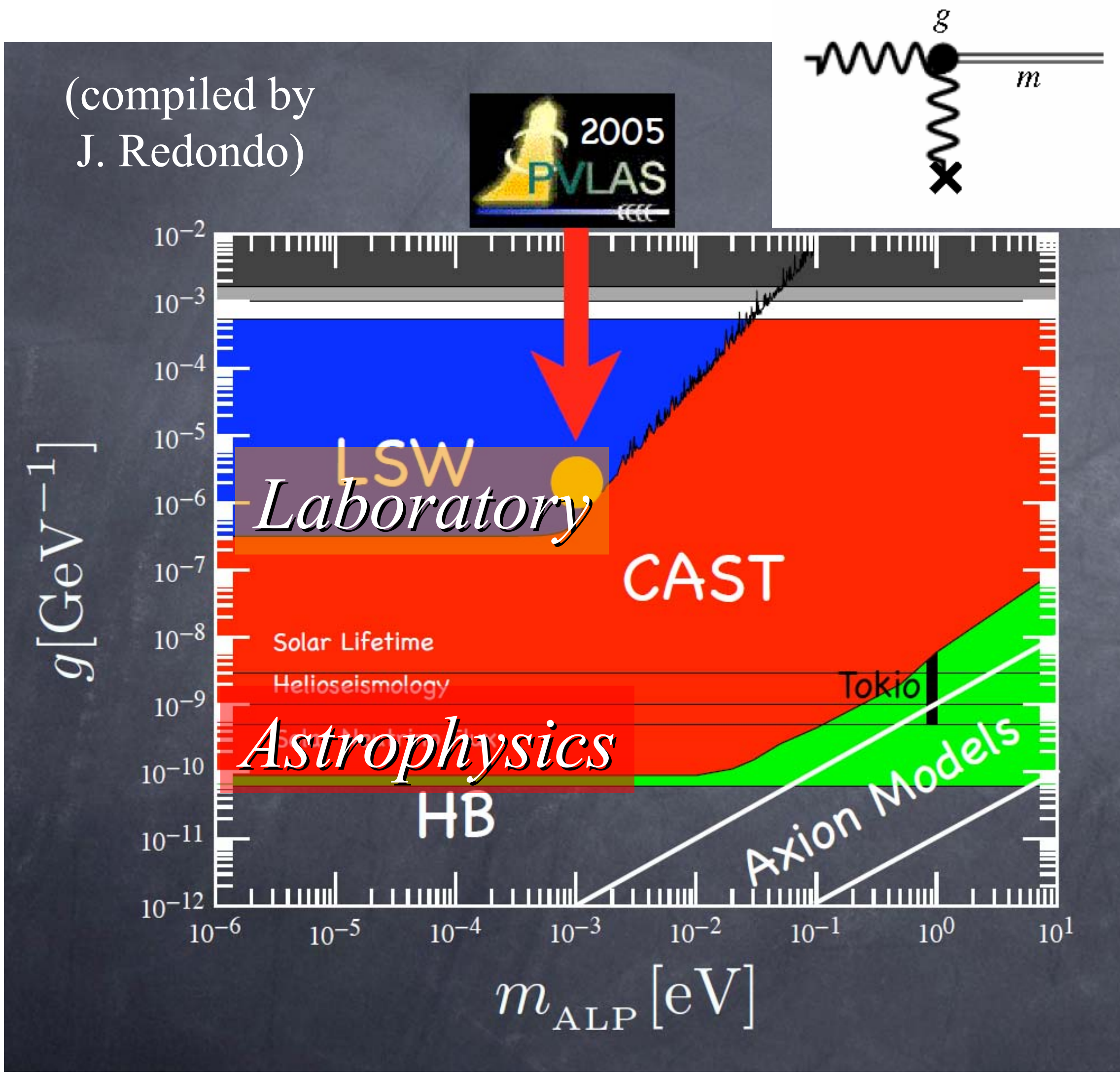
PVLAS 2005/2006:

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…

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

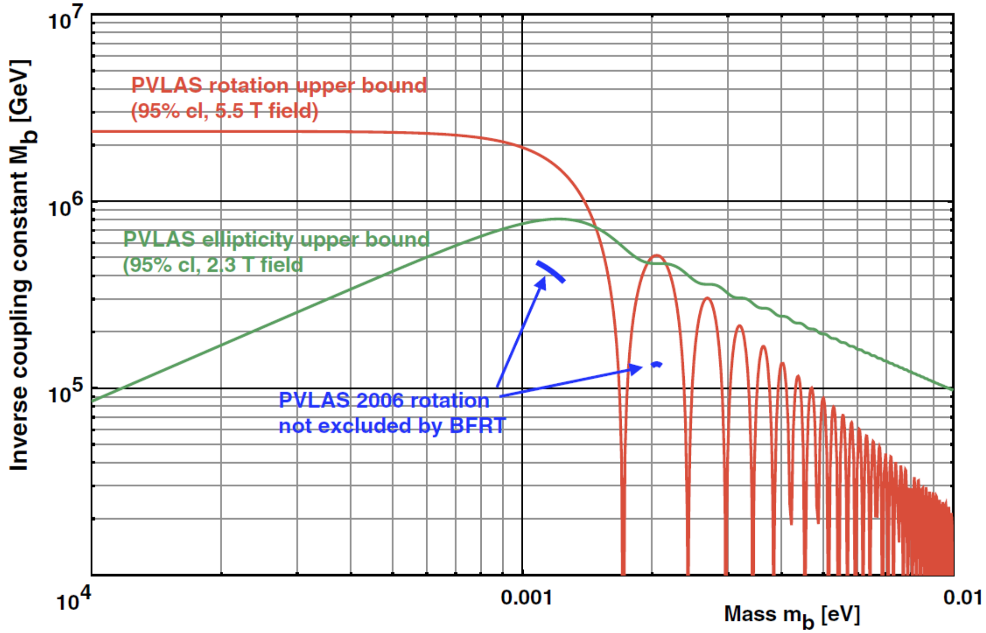
- Masso-Redondo model:
  Different effective theories at keV energies (stars) and at low energies (laboratory),
  WISP production might be suppressed in stars,
  but not in “low energy” environments in the laboratory.
- WISPs occur naturally in string-theory based extensions of the Standard Model.
  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, the field is still alive due to the theoretical insights discussed above.

The Survival of the "Low Energy Frontier"

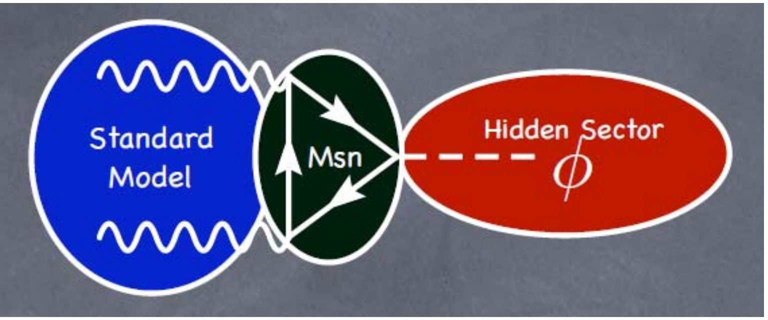
- The discovery of WISPs may be "just around the corner".
- Astrophysics and laboratory experiments complement each other.
- Probing the QCD axion remains a challenge.

- 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:

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

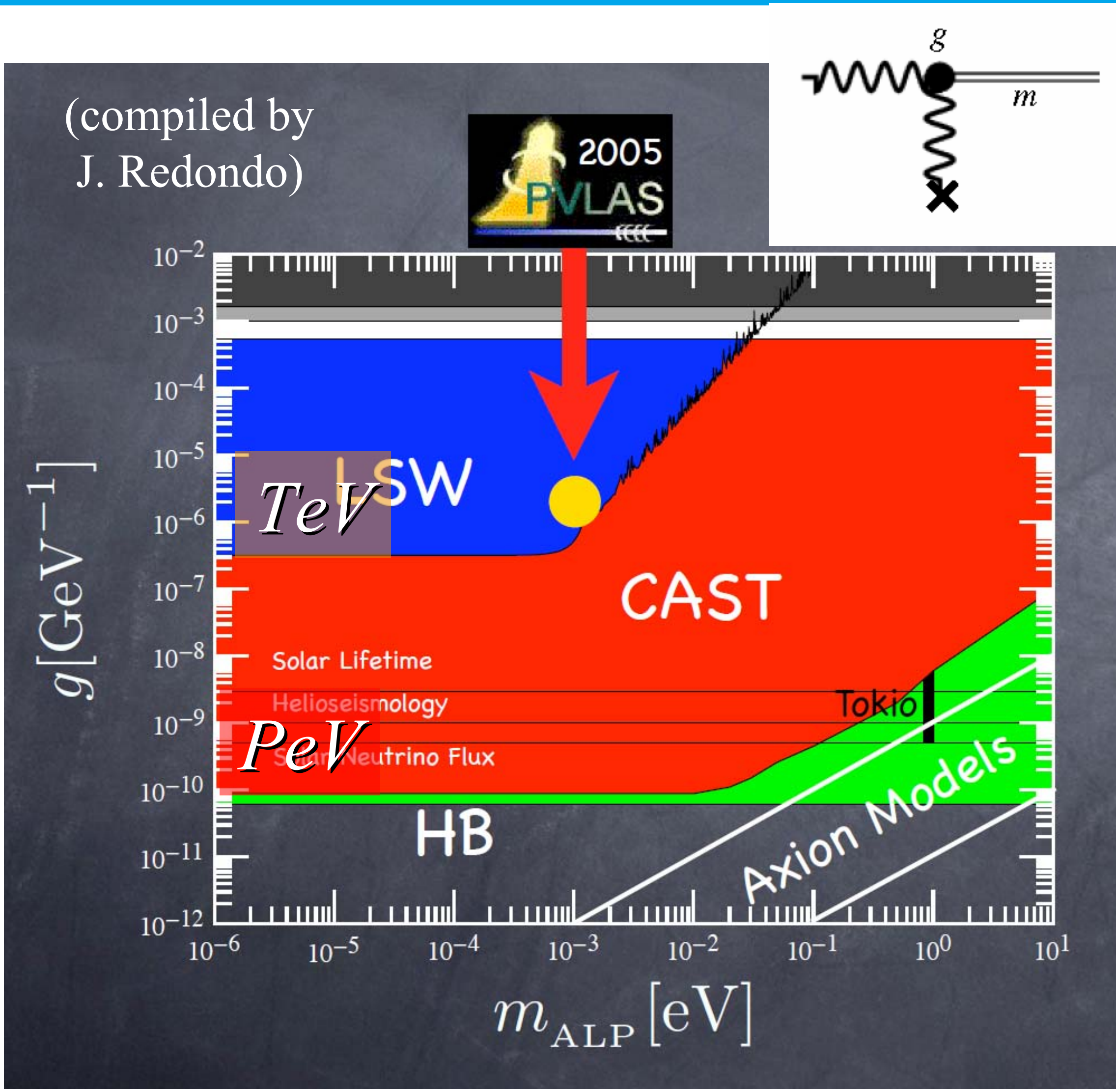
$q = p_\gamma - p_\Phi$
l: length of B field

Note: an 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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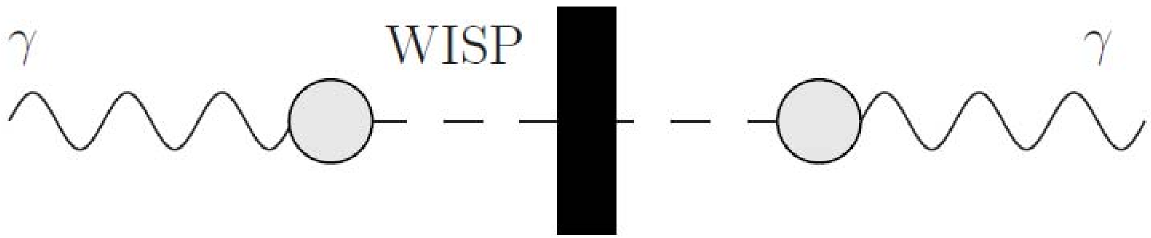
ALPS @ DESY in Hamburg

Approved January 2007.

Final data run December 2009 (end of first phase).

The ALPS Project

Any Light Particle Search @ DESY



A photon regeneration experiment

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

DESY

Leibniz Universität Hannover

LZH LASER ZENTRUM HANNOVER e.V.

UHH Universität Hamburg

Experimental Challenges

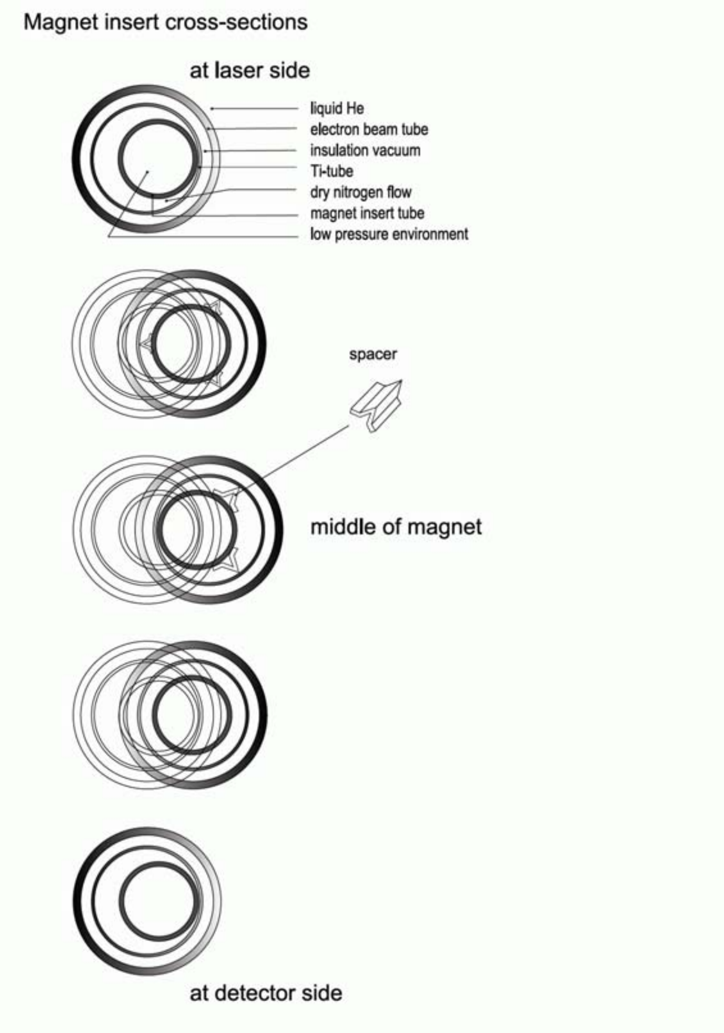
- Large magnetic length
  (we have just one HERA dipole)

- Sensitive low noise detector

- Maximal laser intensity
  - Clear aperture only 14 mm (vertical) on a length of 8.6 m.

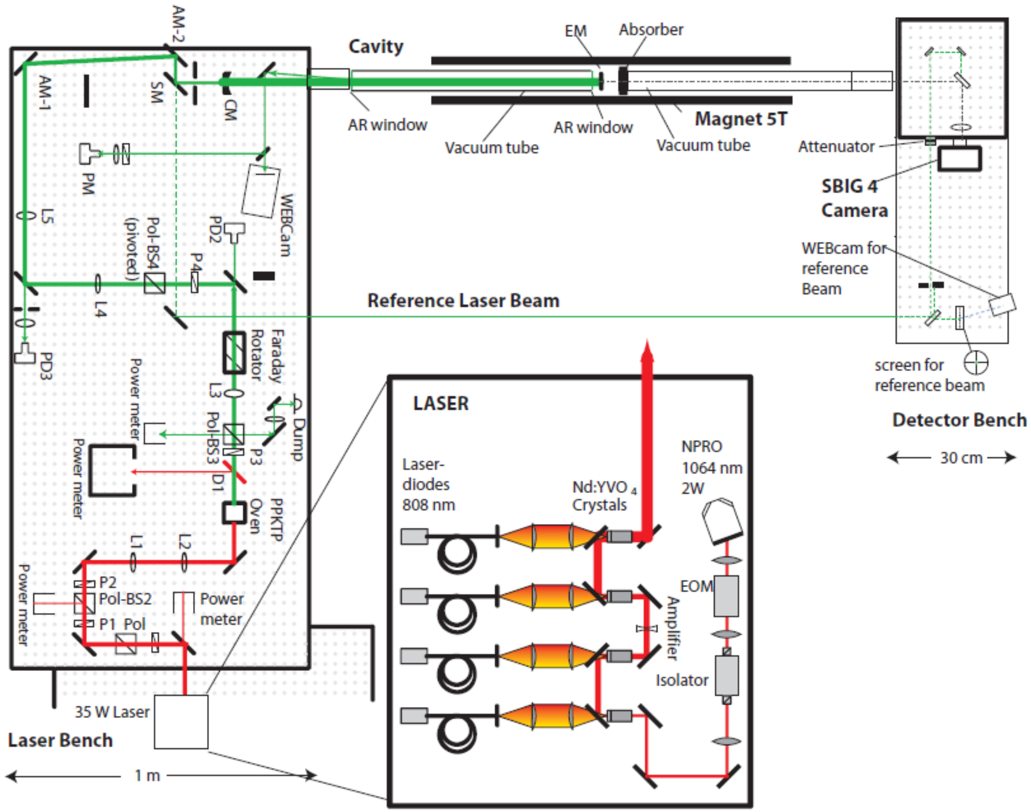
  Laser with very high beam quality (Gaussian beam profile) required.

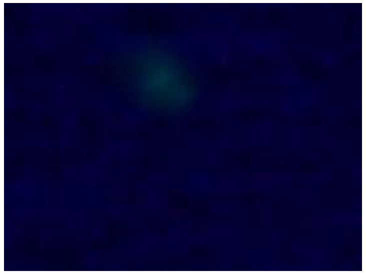
  Essential:
  Collaboration with members of the gravitational wave antenna community.

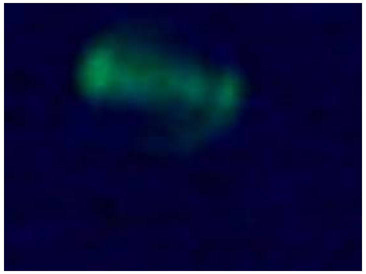


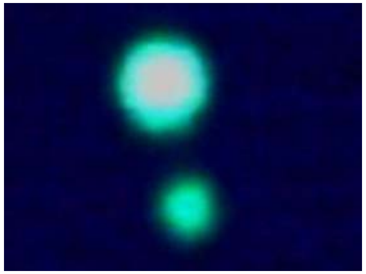
ALPS : first Operation of an optical Resonator

- 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)



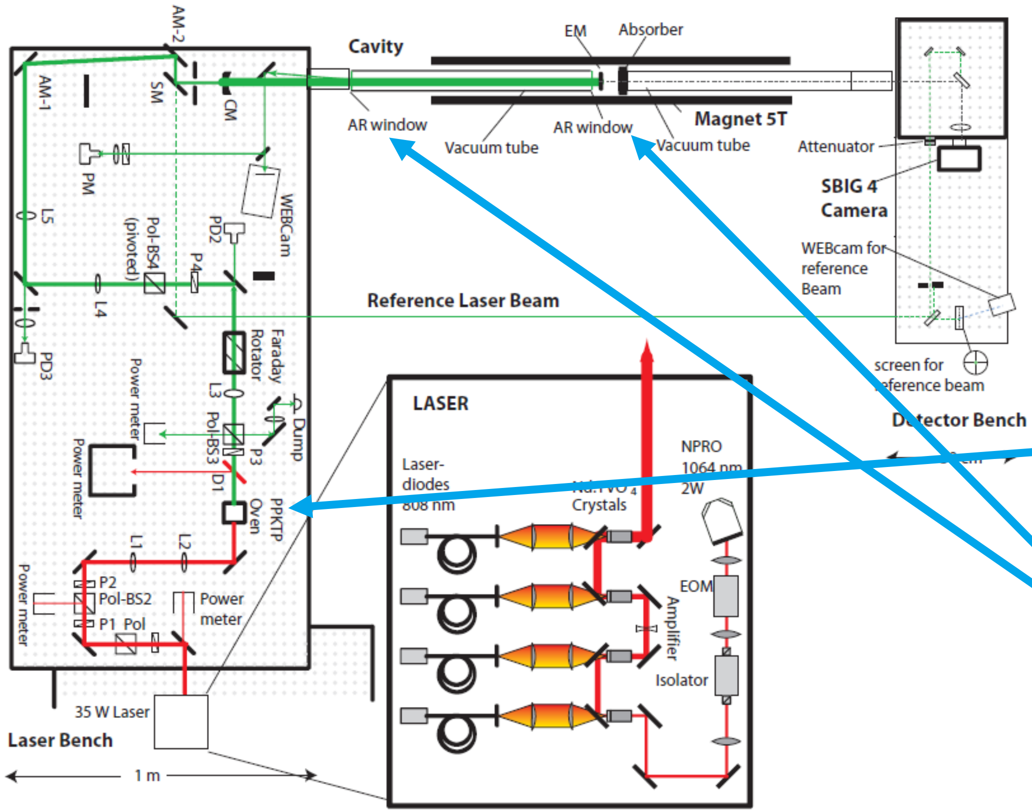

resonator detuned


free running


locked

ALPS : first Operation of an optical Resonator

- Set-up for data published in NIM A, [doi:10.1016/j.nima.2009.10.102](https://doi.org/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!

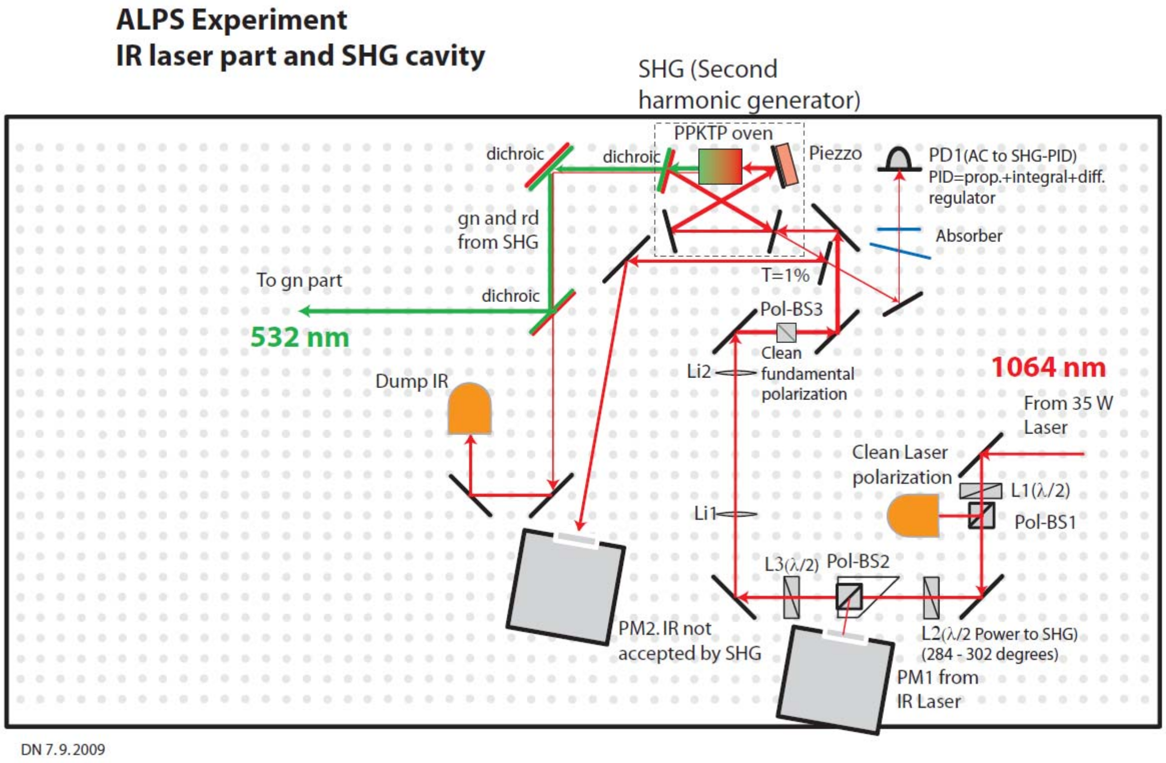
The main limitations were:

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:



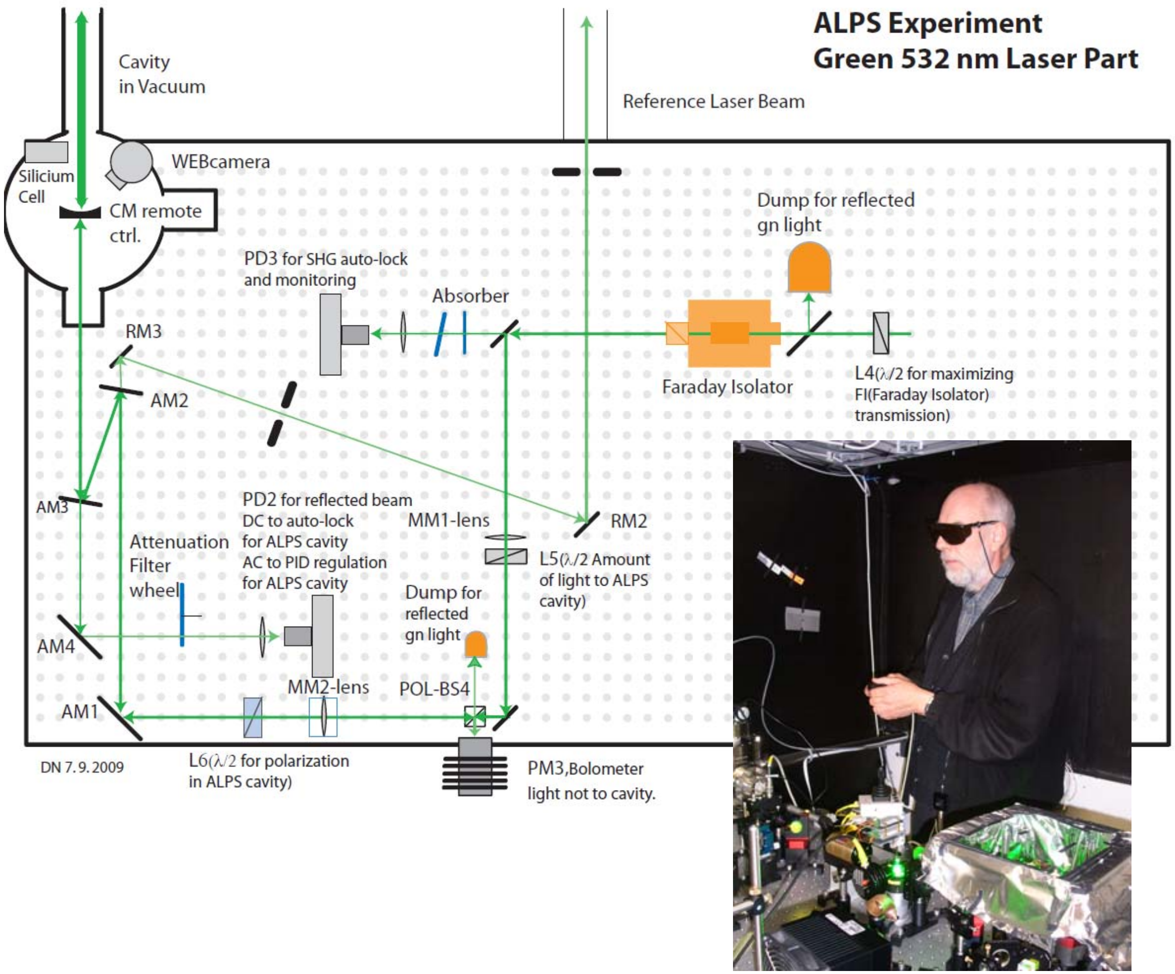
Improved frequency doubling of laser light by use of a second resonator:
now 4 W out of 11 W are achieved (36%).

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:



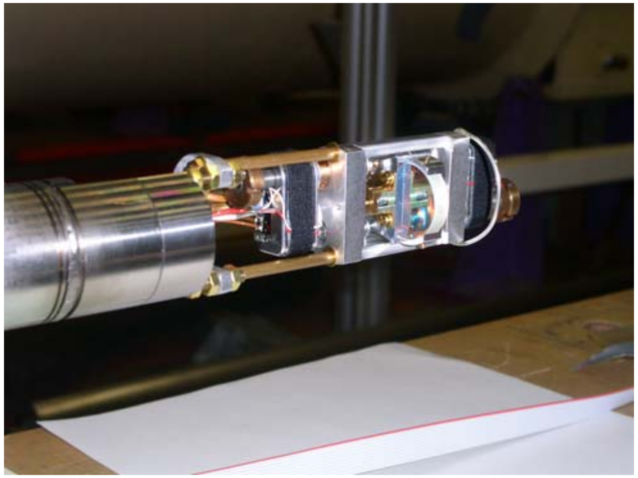
Get rid of AR windows by including the cavity mirrors into the vacuum of the laser beam tube:

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:



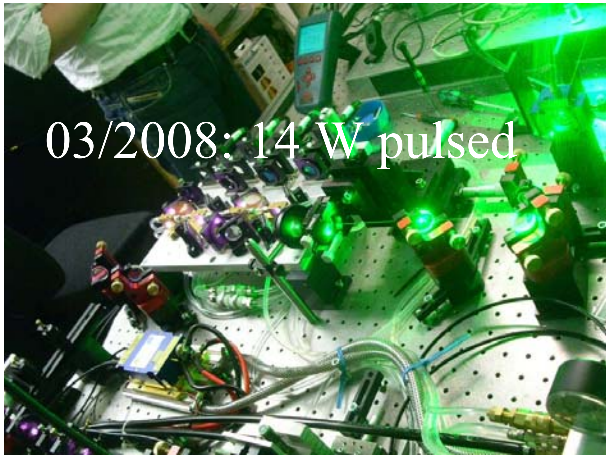
Get rid of AR windows by including the cavity mirrors into the vacuum of the laser beam tube:

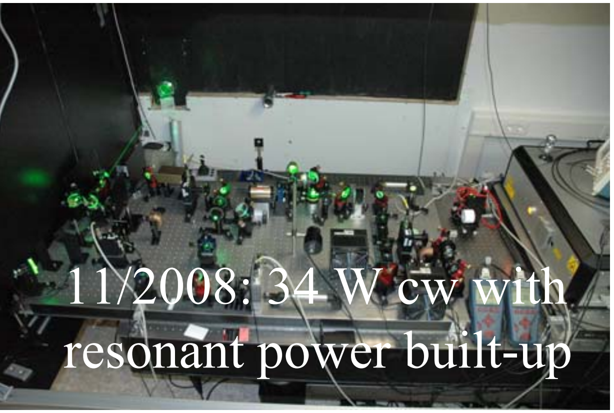
The mirror holder in the centre of the ALPS magnet attached to the laser side vacuum tube was replaced by a new much smaller holder which slides into the tube.

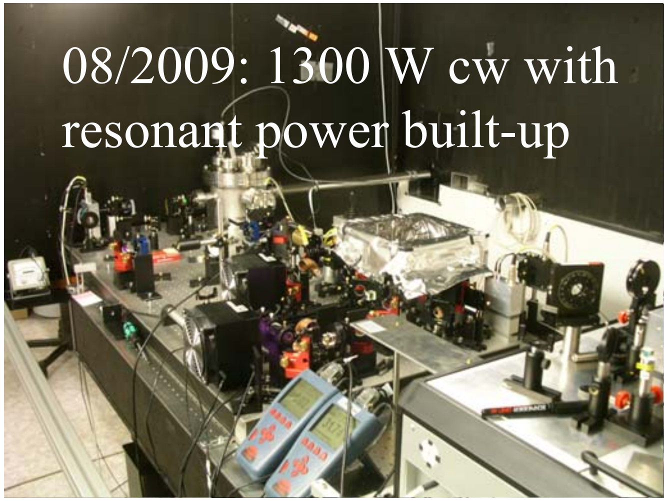
No properly suited small motors (vacuum + 5 Tesla!) are available, but fortunately own improvements of magnet-suited squiggle motors work!

ALPS Upgrades since Spring 2009: Laser

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







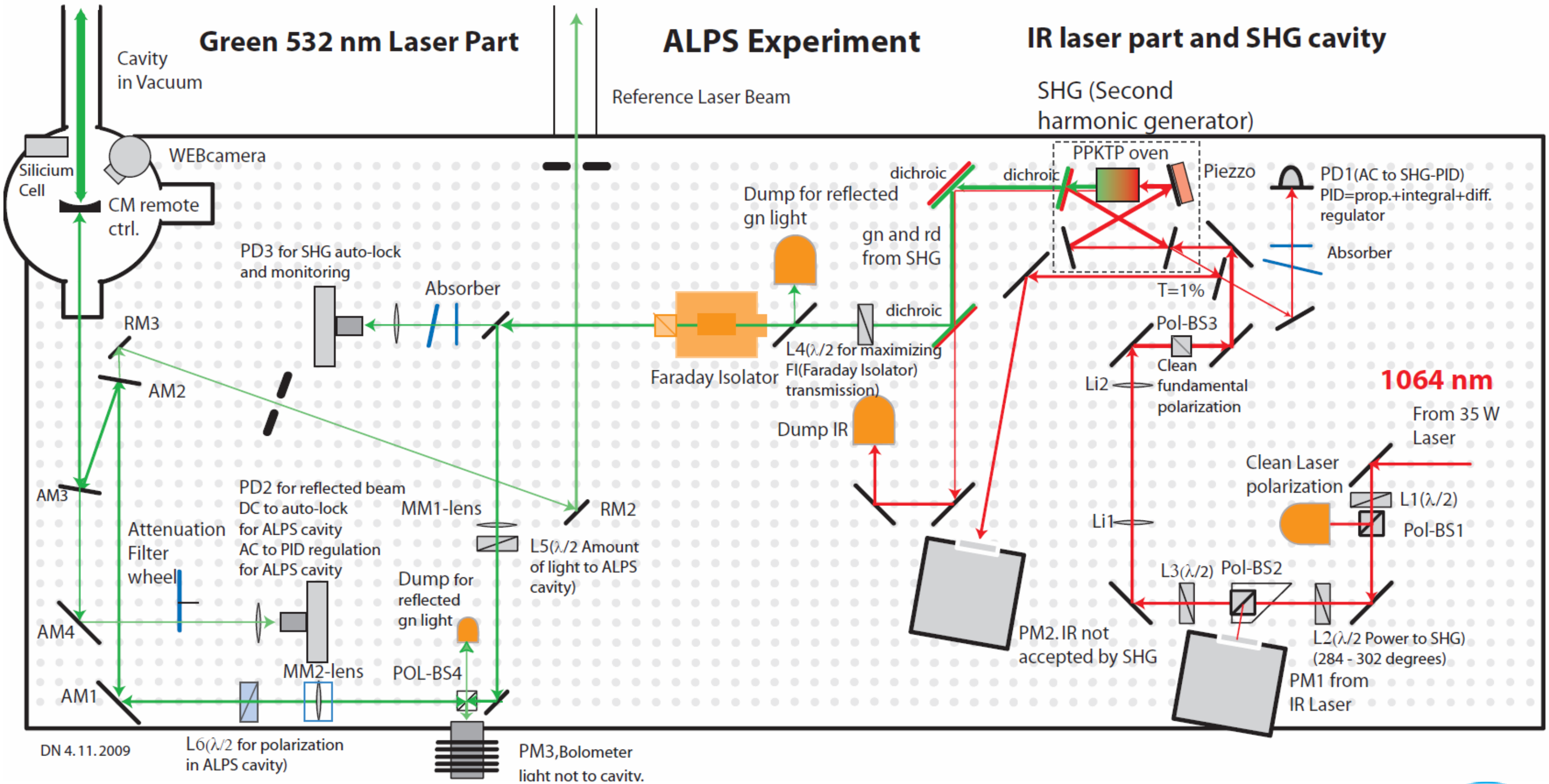
The 1300 W laser power is achieved from 4.4 W built-up in the resonator by a factor of 300.

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!

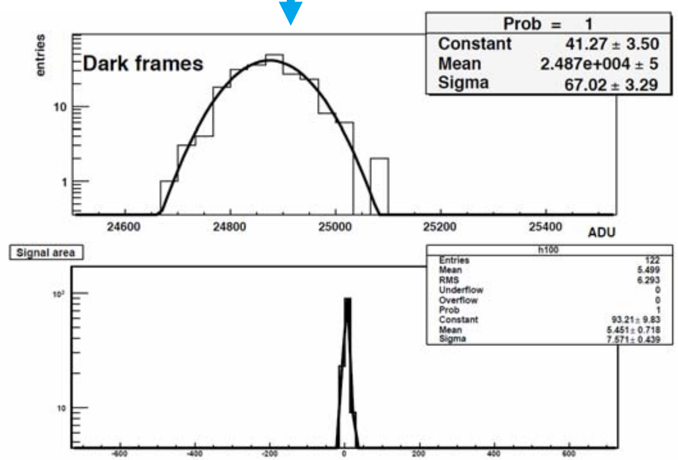
The new ALPS Laser System

- We are running a quite complex and delicate apparatus!



ALPS Upgrades since Spring 2009: Detector

> Replacing the SBIG ST-402 with a PIXIS 1024B:



The new CCD shows much less dark current and read-out noise, a higher QE and the possibility to bin pixels in order to effectively decrease the read-out noise for groups of pixels.

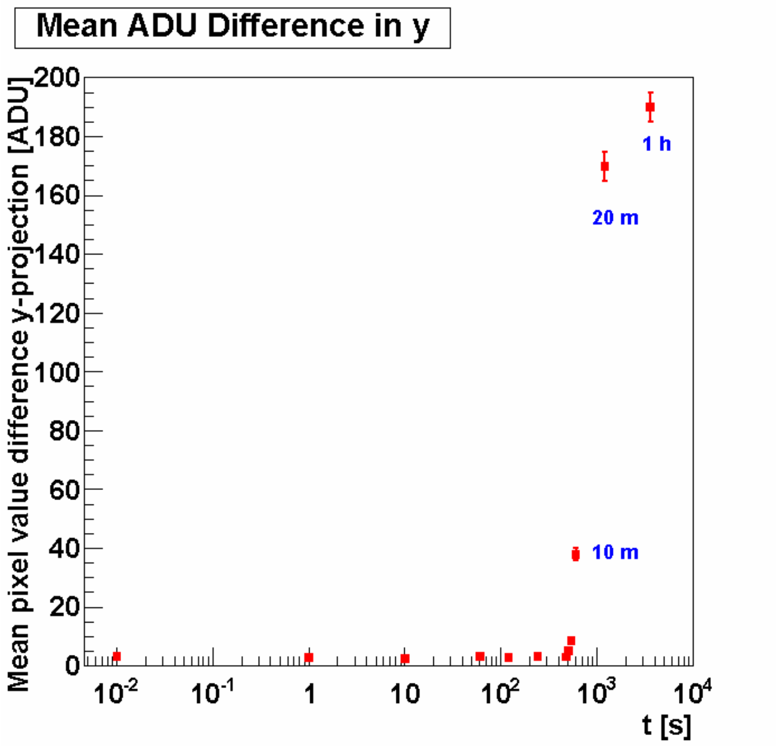
The ADU spectrum of the signal region in dark frames (no light) is much narrower for the PIXIS.

However, the PIXIS shows large frame-to-frame fluctuations which challenge the data analysis.

Overall, with the new CCD the flux sensitivity is increased by a factor of 20.

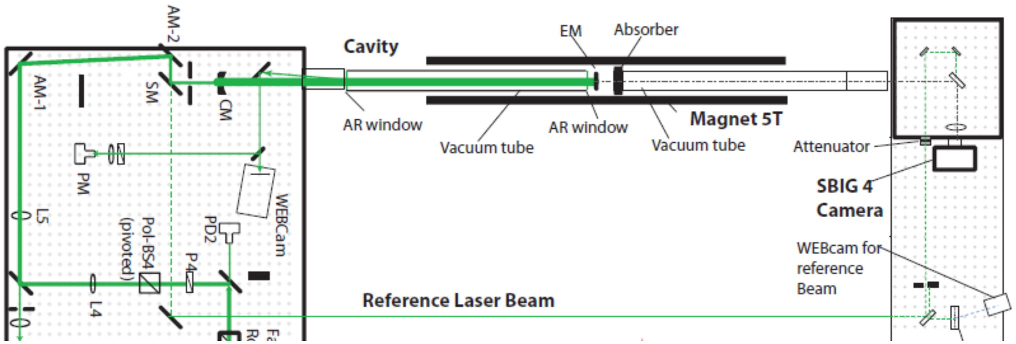
The new ALPS Camera

Liquid cooled PIXIS:1024B from Princeton Instruments



Problem concerning stability of pedestal and/or gain for exposure times larger than about 500 s (2^9!) found.
Reason still not identified.

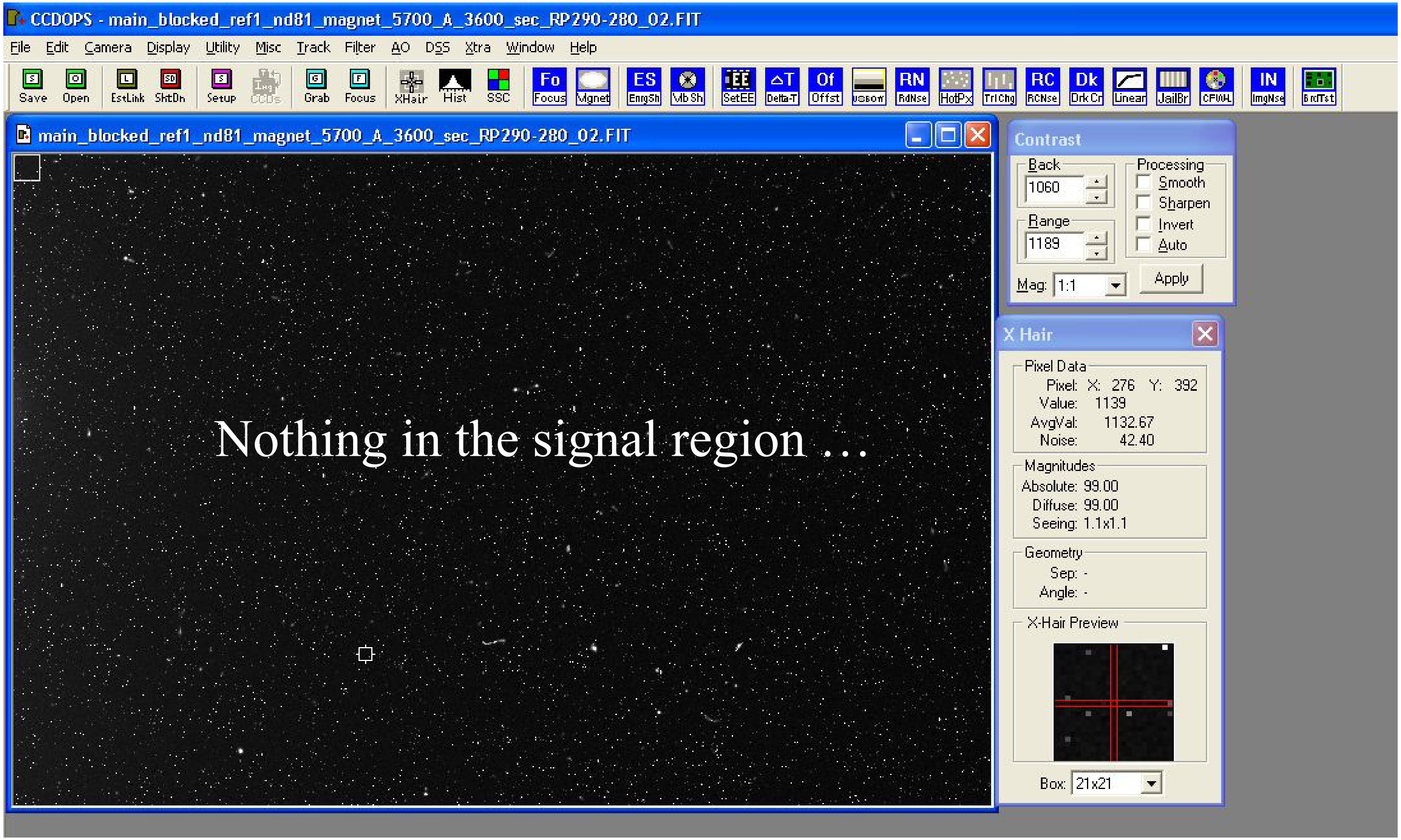
ALPS at Work



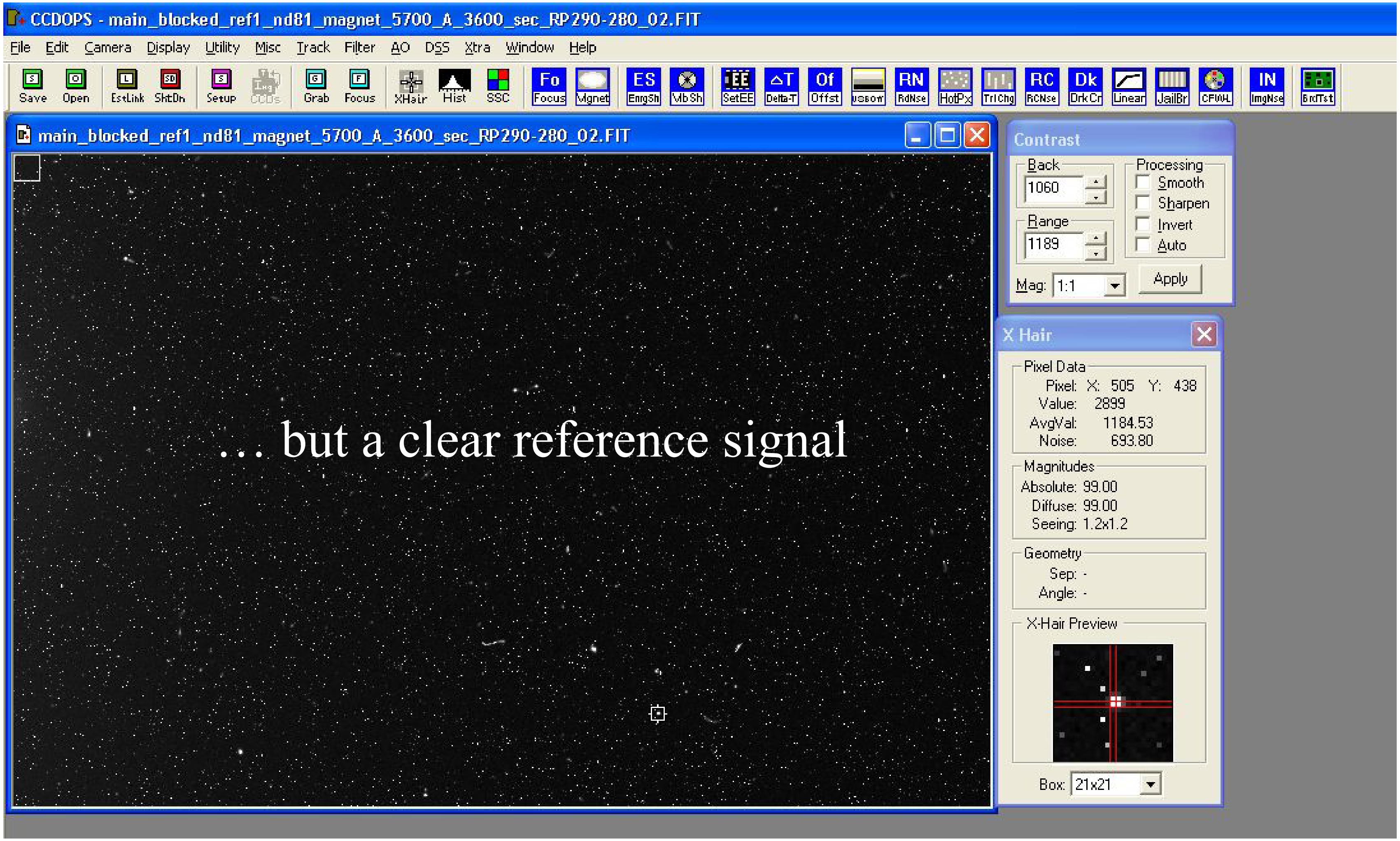
Steps of data taking:

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.
4. Demount detector and detector tube, open tube and reinstall all.
5. Test alignment like in step 1.

One Data Frame (SBIG ST-402)

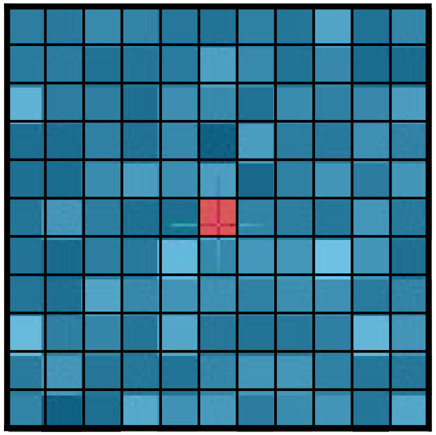


One Data Frame (SBIG ST-402)

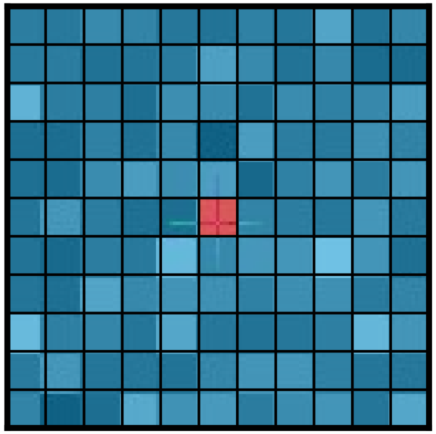


Principles of the Data Analysis

- The data consist of CCD frames with an exposure of one hour.
- The photons from reconverted WISPs would arrive in a known pixel of the CCD.
- 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 PIXIS camera, not the raw pixel value, but 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.



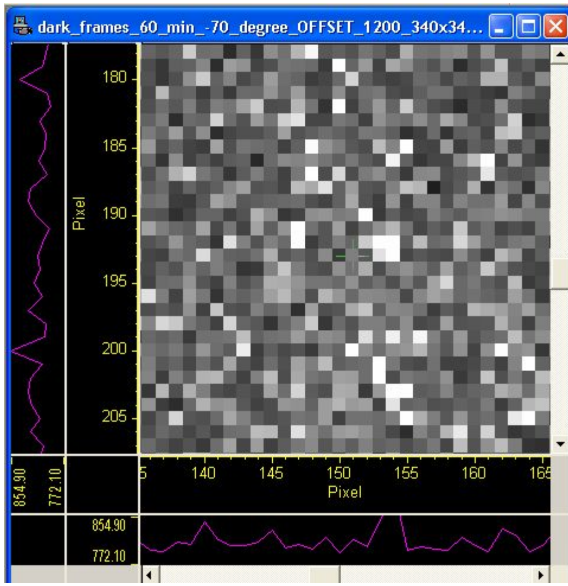
Basics of the Data Analysis



- This difference is compared between data and dark frames. The difference of both differences is interpreted as a “signal” for light shinning through a wall.
- The analysis is performed not only for the signal pixel, but for each pixel in the 11·11 grid. In 120 pixels no “signal” is expected so that the distribution of the differences should follow a Gaussian centered at zero. Any deviation is a hint for systematic uncertainties induced for example by cosmics or “hot” pixels.

Data Selection

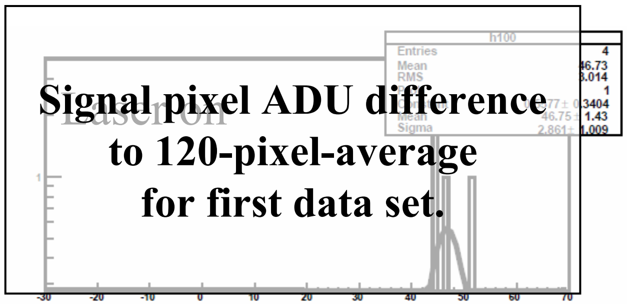
- A region of about 25·25 pixels around the signal pixel is visually scanned for cosmics or other spurious activity.
- The analysis method mentioned above is performed in two steps:
  - in a first iteration all pixels are "masked", where the pixel values exceed the 120-pixel-averages by more than 30 ADU.
  - in the second iteration these masked pixels are skipped for calculating the averages.

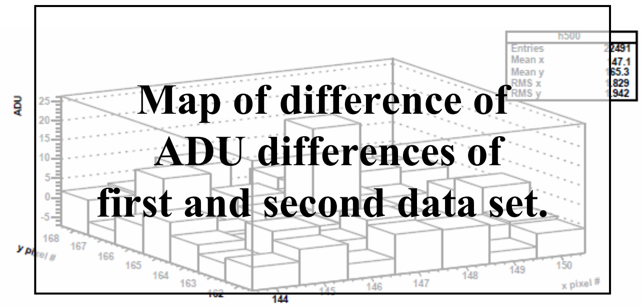


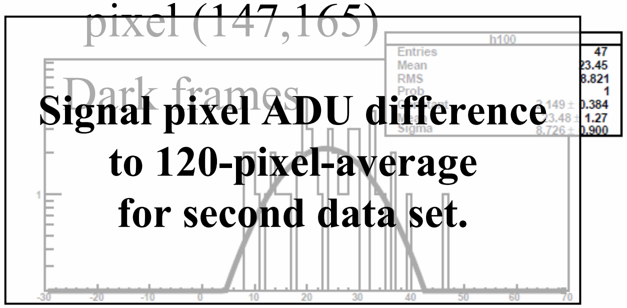
- All distributions are checked for unexpected deviations. In all cases they could be tracked to individual frames with cosmics or hot pixels which have been overlooked before.
- This procedure turns out to be rather robust and insensitive to details like the 30 ADU cut mentioned above.
- This method gives essentially the same results as the another frame fluctuation correction method based on a 2-dimensional function.

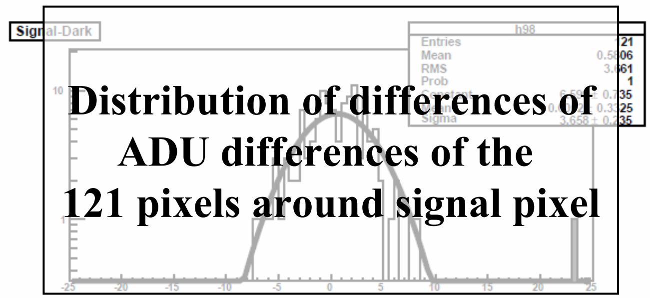
A Glimpse into the Data Analysis

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



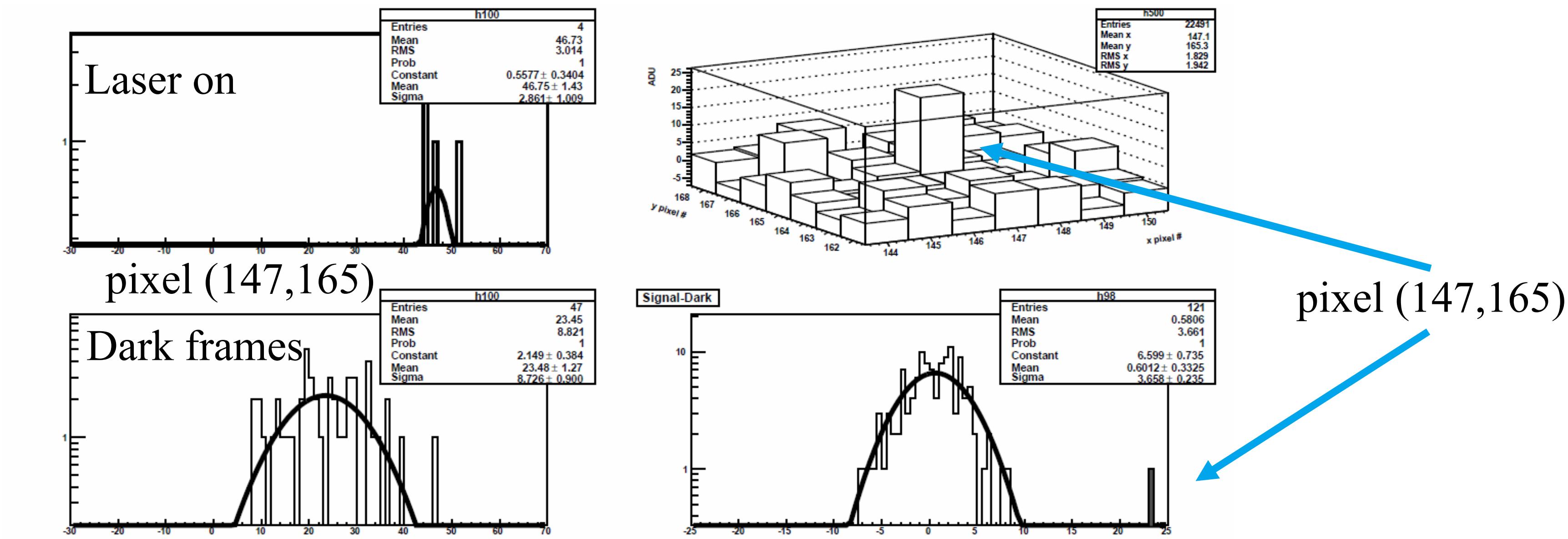






A Glimpse into the Data Analysis

- 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 (9.0±1.2) mHz ($3.3 \cdot 10^{-21}$ W) is detected which agrees nicely to the expectation.

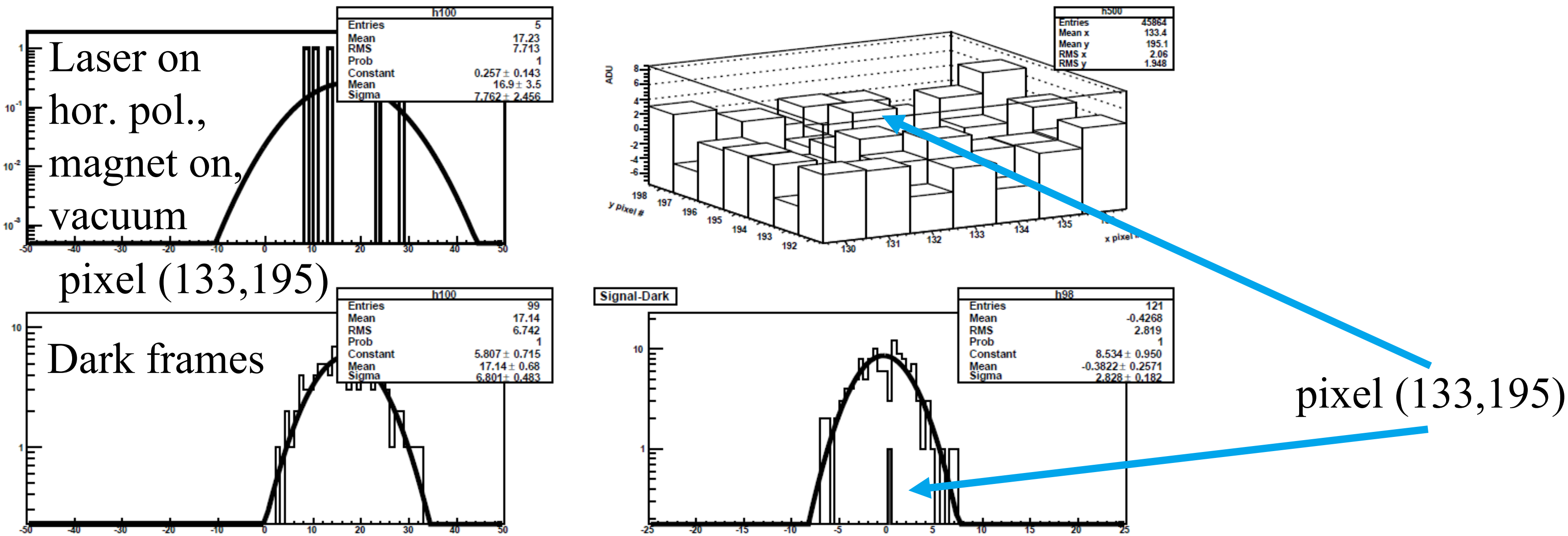
A Glimpse into the Data Analysis

> Some new data set:

Data	binning	Signal pixel	frames	selected	
Dark Frame Series 090828-090907	X: 3;1022;3;340 Y: 1;1020;3;340	(151,193) with reference beam	136	122	93%
Dark Frame Singles 090904-090907			17	16	94%
Laser-on-hor-Magnet-on 090827			9	9	100%
Laser-on-vert-Magnet-on 090907			2	2	100%
Laser-on-vert-Magnet-off 090907			1	1	100%
Dark Frame Series Shutter closed 091023-091027	X: 3;1022;3;340 Y: 2;1024;3;341	(133,195) without reference beam	80	65	81%
Dark Frame Series Shutter open 091027-091030			45	34	76%
Laser-on-hor-Magnet-on 091030			5	5	100%
Laser-on-hor-Magnet-on-0.18mb 091028-091029			10	8	80%
Laser-on-vert-Magnet-on-0.18mb 091026-091027			9	8	89%
Low Intensity Test 090918	X: 1;1023;3;341 Y: 1;1023;3;341	(147,165) without reference beam	4	4	100%
Dark Frame Series 090919-090921			59	47	80%
Laser-on-hor-Magnet-on 090922			2	2	100%
Laser-on-vert-Magnet-on 090922			6	6	100%

A Glimpse into the Data Analysis

> Example for the analysis:



From Gaussians fitted to the data:

Δmean	Δwidth
-0.24±3.54	0.96±2.50

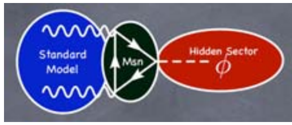
In none of the preliminary data analyses any evidence for WISP production shows up.

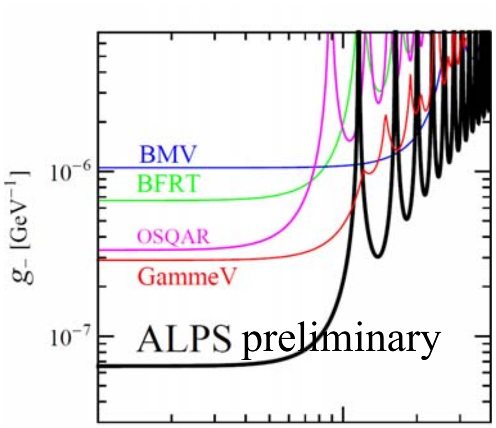
Preliminary Limits

Polarization	n-1	$P(\gamma \rightarrow \Theta \rightarrow \gamma)$ (95%CL)
horizontal	0	$2.3 \cdot 10^{-25}$
vertical	0	$3.0 \cdot 10^{-25}$
hor.+vert.	0	$1.0 \cdot 10^{-25}$

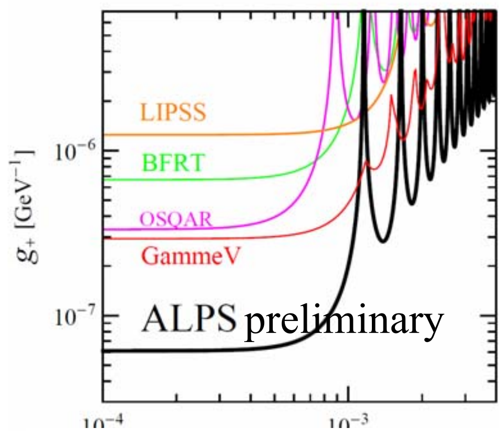
Preliminary Results for the Vacuum Data

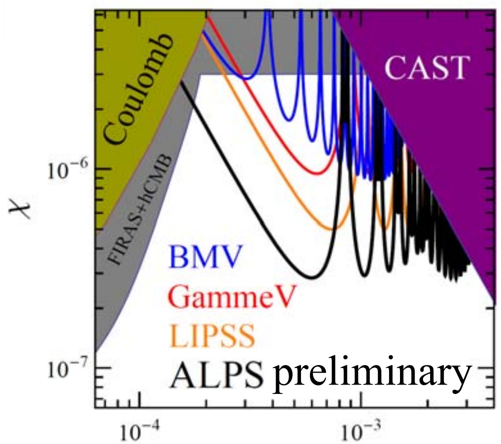
- ALPS is the most sensitive experiment for WISP searches in the laboratory. For axion-like particles, ALPS probes physics at the "multi-10-TeV scale"!





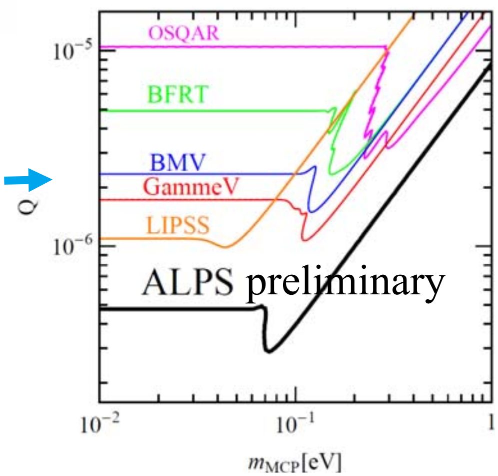
pseudoscalar
and
scalar
axion-like particles





hidden sector photons
and
minicharged particles

Filling a gap remaining from astrophysics and other experiments!



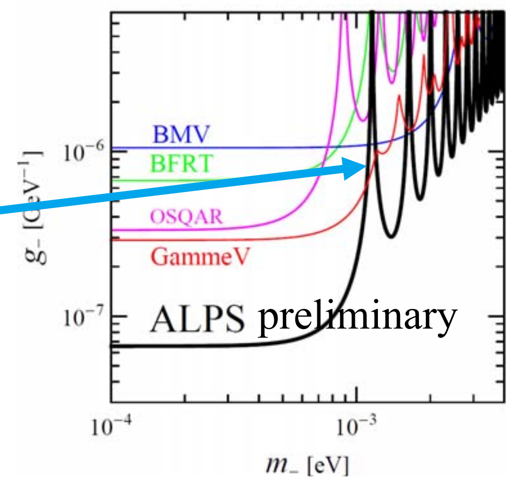
DESY

A new Method to extend the Mass Range

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

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

$$\textit{with } q = p_\gamma - p_\Phi \text{ , } L = \textit{length of B field}$$



- 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.*

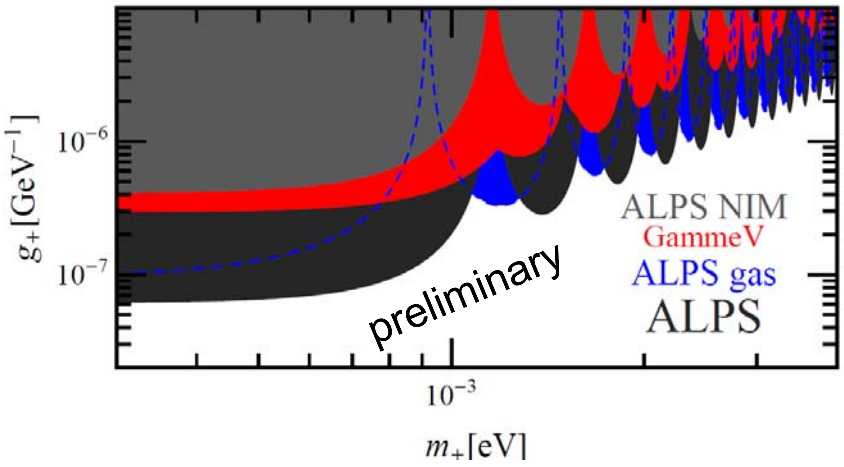
- We apply this approach by taking data with a pressure of 0.18 mb of Argon in the laser and detector beam tubes.

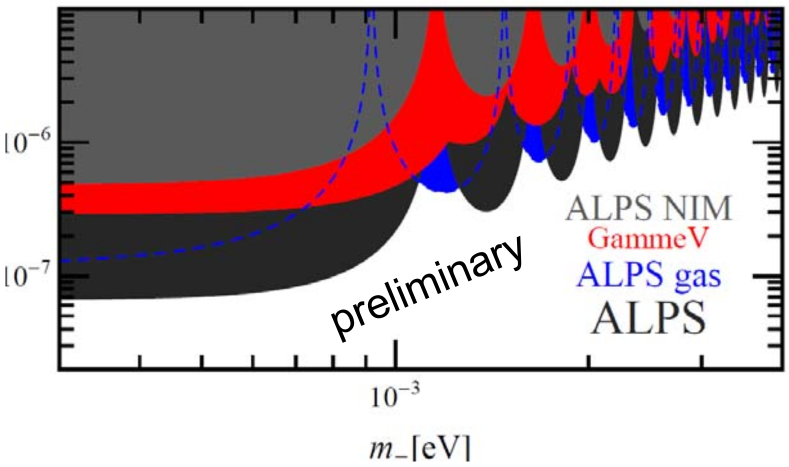
Preliminary Limits

Polarization	n-1	$P(\gamma \rightarrow \Theta \rightarrow \gamma)$ (95%CL)
horizontal	$5.0 \cdot 10^{-8}$	$1.1 \cdot 10^{-24}$
vertical	$5.0 \cdot 10^{-8}$	$3.1 \cdot 10^{-24}$
hor.+vert.	$5.0 \cdot 10^{-8}$	$1.8 \cdot 10^{-24}$

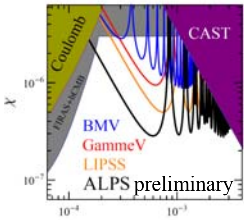
Preliminary Results for the Argon Data

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



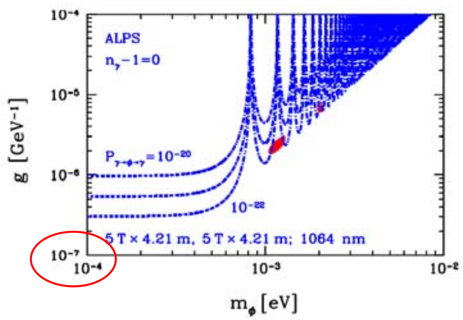


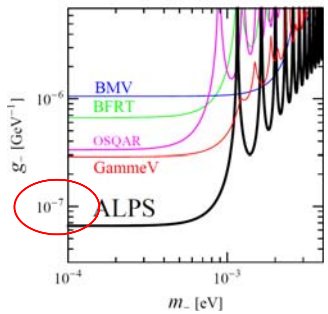
- To close the gaps for hidden sector photon searches, a further data run with a pressure of about 0.11mb and 0.14mb in laser and detector tubes was performed. Note: these data do not need any magnetic field.



ALPS Summary

- Since spring 2009 the apparatus was improved considerably:
  - Primary laser power: factor of 5 (10 announced)
  - Power built-up in resonator: factor of 7.5·2 (15 announced) polarization controllable!
  - Detector sensitivity factor of 20 (10 announced)
- ALPS is now in the forefront of experiments searching for WISPs.
  - Aims as given in the LoI DESY 07-014, hep-ex/0702023 surpassed:





  - The limitations of the set-up are understood.
  - ALPS is a little less expensive than the investments approved!

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Outlook

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

Laser Experiments: History & Presence

Experiment	Reference	$\Delta\theta$	ψ	LSW
ALPS (DESY/D) "**A**xion-**L**ike **P**article **S**earch"	arXiv:0905.4159	✘	✘	✔
BFRT (**B**NL-**F**ermilab-**R**ochester-**T**rieste)	Phys.Rev.**D47**(1993)	✔	✔	✔
BMV (LULI/F) "**B**iréfringence **M**agnétique du **V**ide"	Phys.Rev.Lett.**99** (2007) Phys.Rev.D**78** (2009)	✘	✘	✔
GammeV (Fermilab/USA) "**Gamma** to **meV** particle search"	Phys.Rev.Lett.**100** (2008) Phys.Rev.Lett.**102** (2009)	✘	✘	✔
LIPSS (Jefferson Lab/USA) "**LI**ght **P**seudoscalar or **S**calar particle **S**earch"	Phys.Rev.Lett.**101** (2008) arXiv:0810.4189	✘	✘	✔
OSQAR (CERN/CH) "**O**ptical **S**earch for **QED** vacuum magnetic birefrin-gence, **A**xions and photon **R**egeneration"	Phys.Rev.D**78** (2008)	✘	✘	✔
PVLAS (INFN/I) "**P**olarizzazione del **V**uoto con **LAS**er"	Phys.Rev.Lett.**96** (2006) Erratum-ibid.**99** (2007) Phys.Rev.D**77** (2008)	✔	✔	(✔)
Q&A (Hsinchu/Taiwan) "**Q**ED & **A**xion"	Mod.Phys.**A22** (2007)	✔	✘	✘

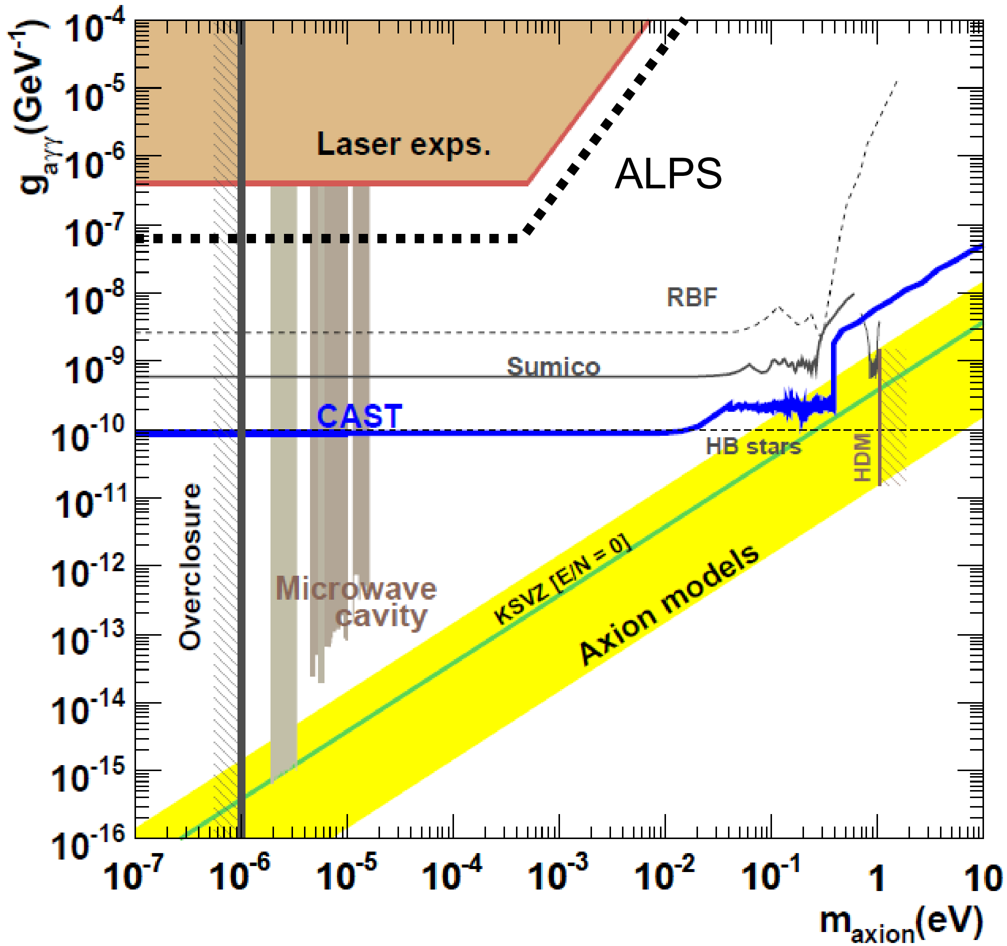
Markus Ahlers
July 13, 2009

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.



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

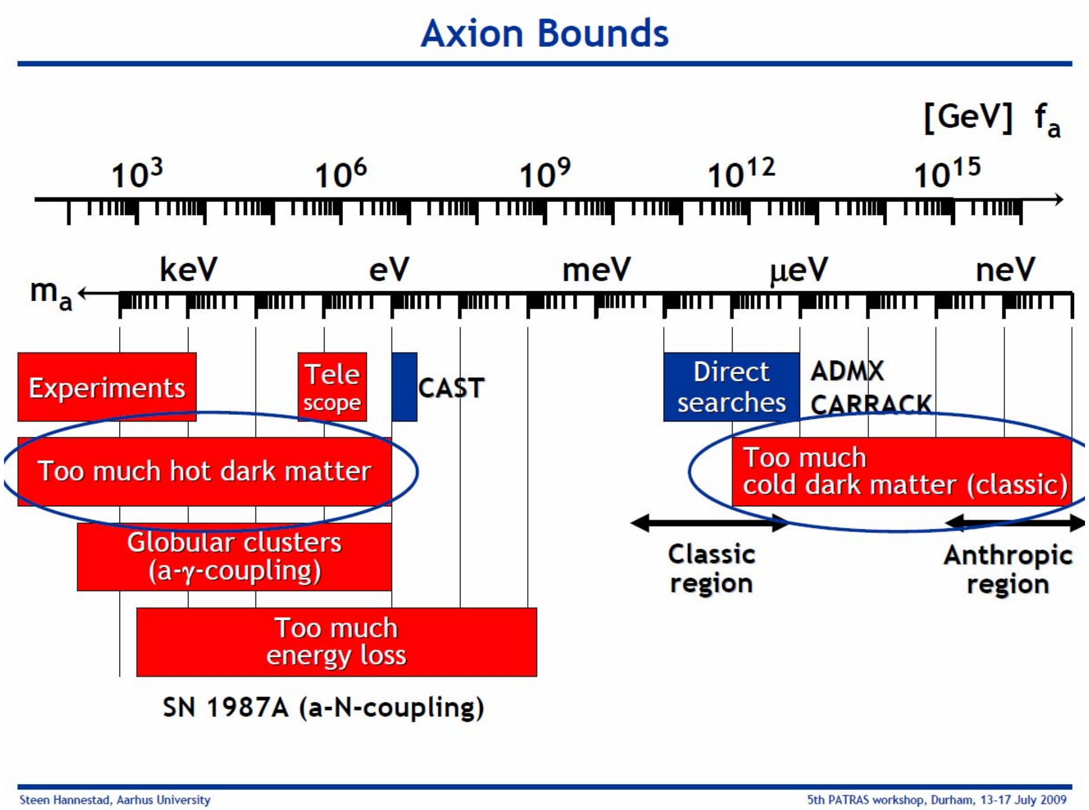
Outlook

- The world-wide activities in this research field are strengthening.
- 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 Laser Zentrum Hannover and the Albert Einstein Institute have already drafted a plan for a possible ALPS-extension.
- However, is this worthwhile to do?

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.
- Dark Energy may correspond to a field of meV mass particles.



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

Hints for ALP Physics?

Remind:

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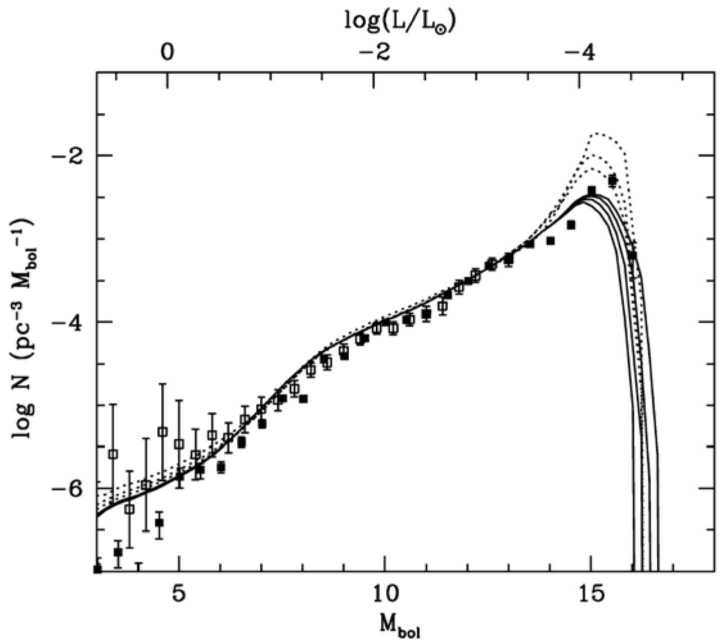
Astrophysics:

- *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]

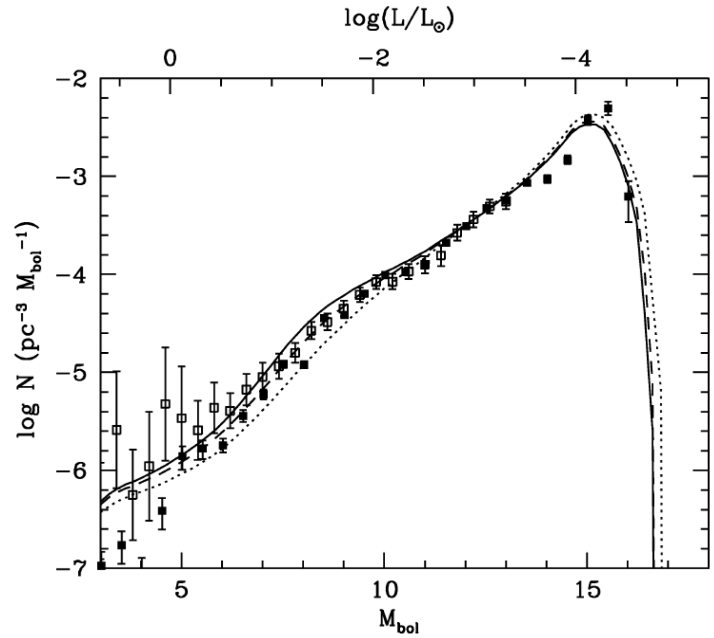
Hints for ALP Physics: White Dwarf Cooling

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

Theory without axions



Theory with axions



Hints for ALP Physics: Cosmological Gamma-Ray Propagation

TeV photons should be absorbed by e^+e^- pair production due to interaction with the extragalactic backround light (EBL):

$\gamma_{TeV} + \gamma_{eV} \rightarrow e^+ + e^-$

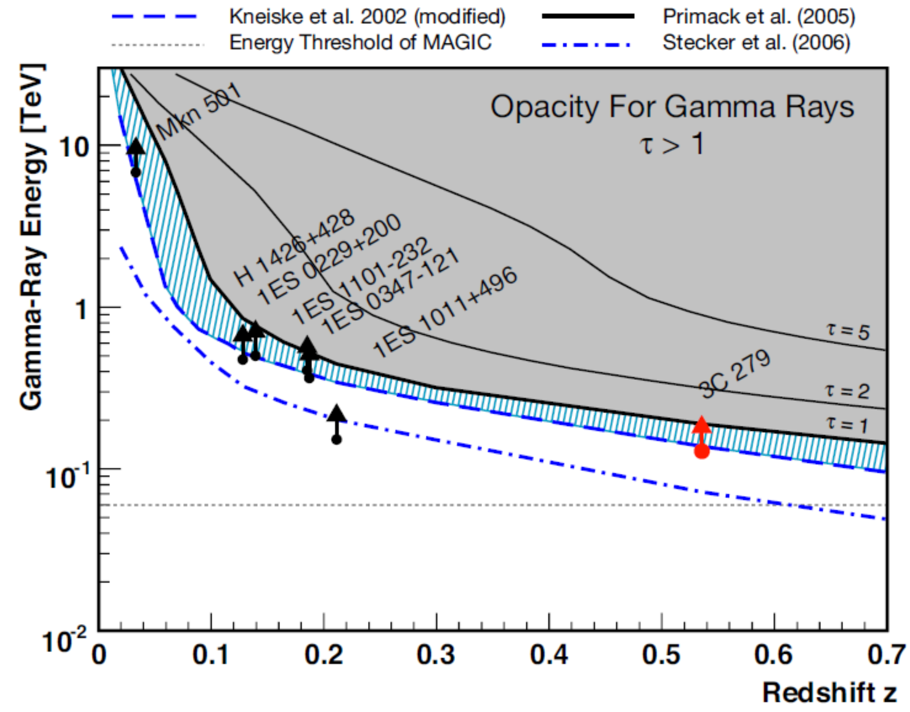
However, the spectra of distant quasars do hardly show any absorption.

The upper limit on the EBL derived from these observations do not leave much margin to lower limits on the EBL determined from astrophysics.

Very-High-Energy Gamma Rays from a Distant Quasar: How Transparent Is the Universe?

The MAGIC Collaboration*

Science **320**, 1752 (2008); DOI: 10.1126/science.1157087



Hints for ALP Physics: Cosmological Gamma-Ray Propagation

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

TeV photons from distant Blazars escape interaction with intergalactic light by "hiding" temporarily as ALPs.

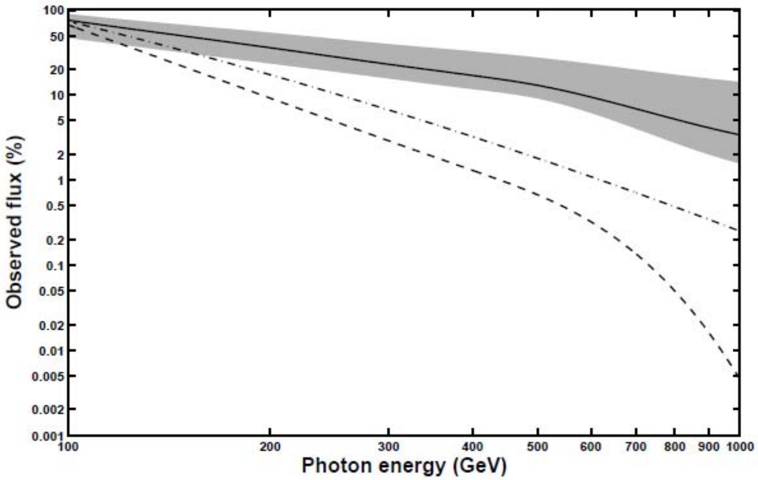
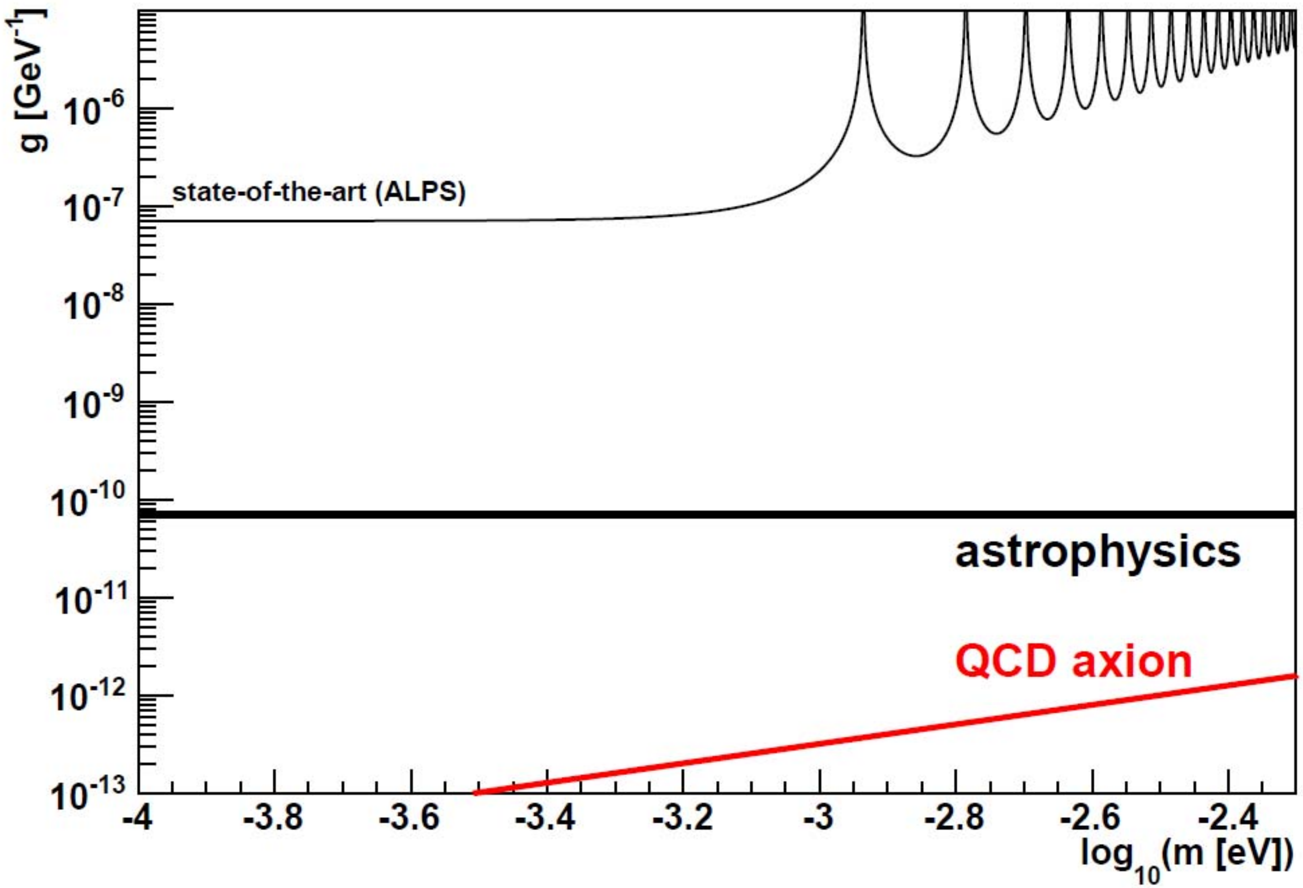


FIGURE 2. The two lowest lines give the fraction of photons surviving from a source at the same distance of 3C 279 without the oscillation mechanism, for the "best-fit model" of EBL (dashed line) and for the minimum EBL density compatible with cosmology [2]. The solid line represents the prediction of the oscillation mechanism for $B \simeq 10^{-9}$ G and $L_{\mathrm{dom}} \simeq 1$ Mpc within the "best-fit model" of EBL. The gray band is the envelope of the results obtained by independently changing **B** and L_{dom} within a factor of 10 about their preferred values.

A possible Scenario for ALPS II

- Still a way to go!



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.

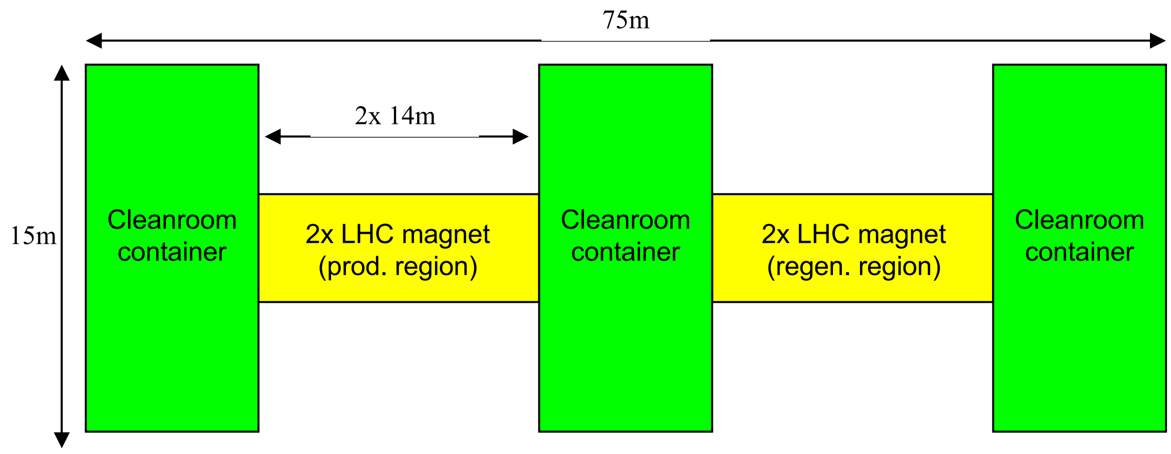
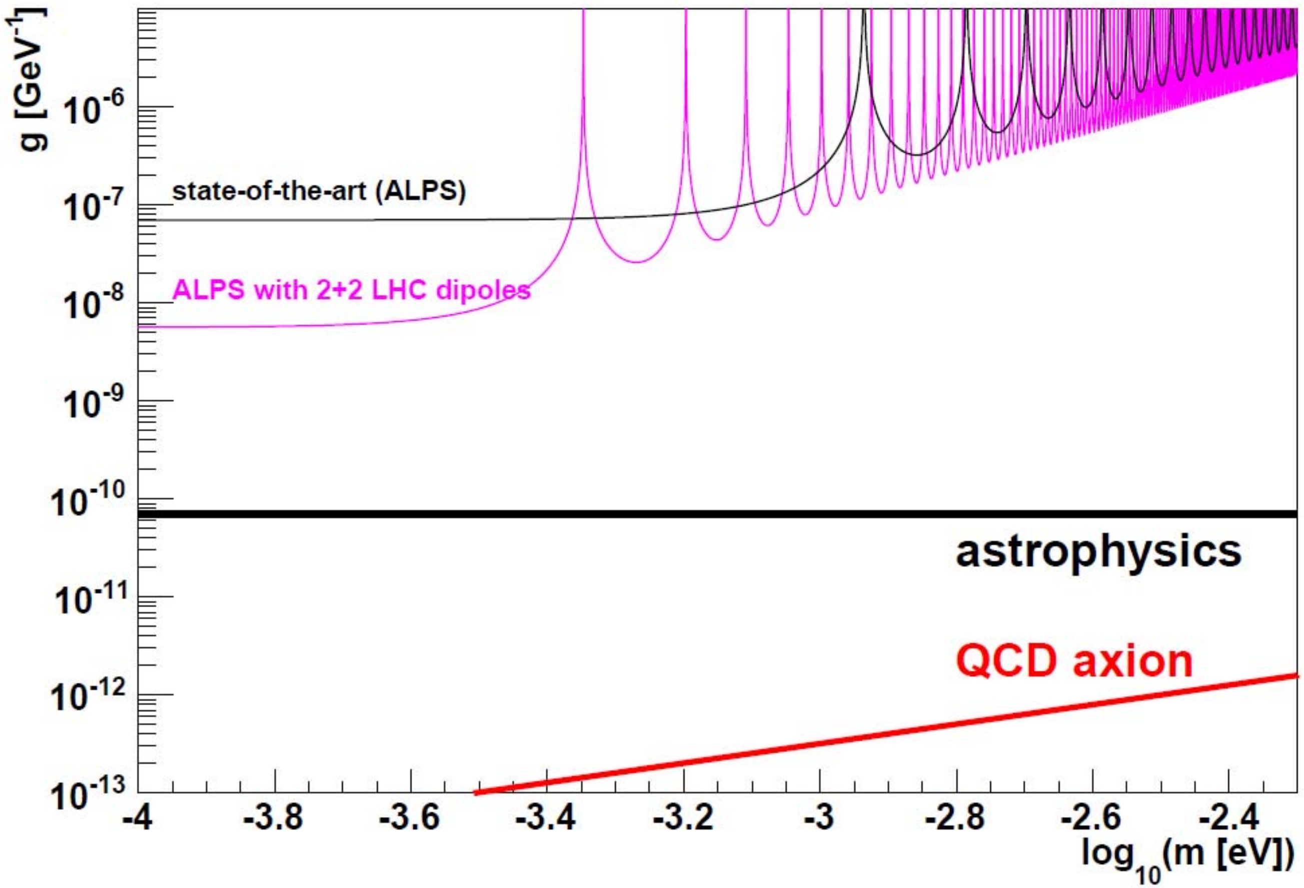


Fig. 1: ALPS II - setup of LHC magnets and cleanroom containers within hall 55. The magnets need cryogenic infrastructure. The cleanroom containers will host all optics, electronics and working areas.

A possible Scenario for ALPS II

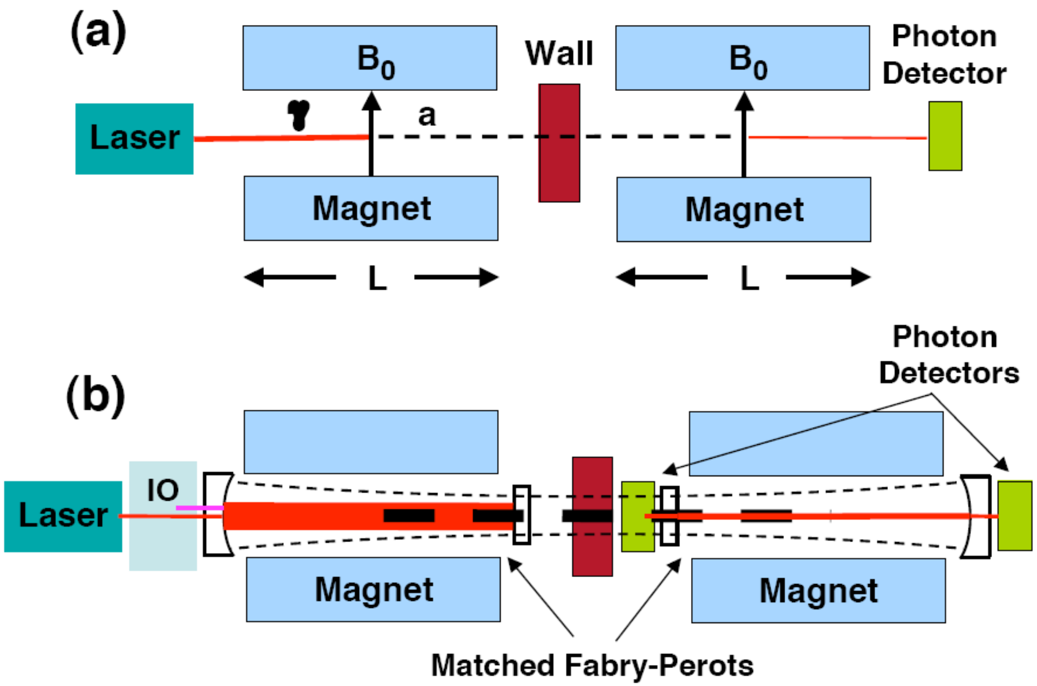
- Invest into more powerful magnets.



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.



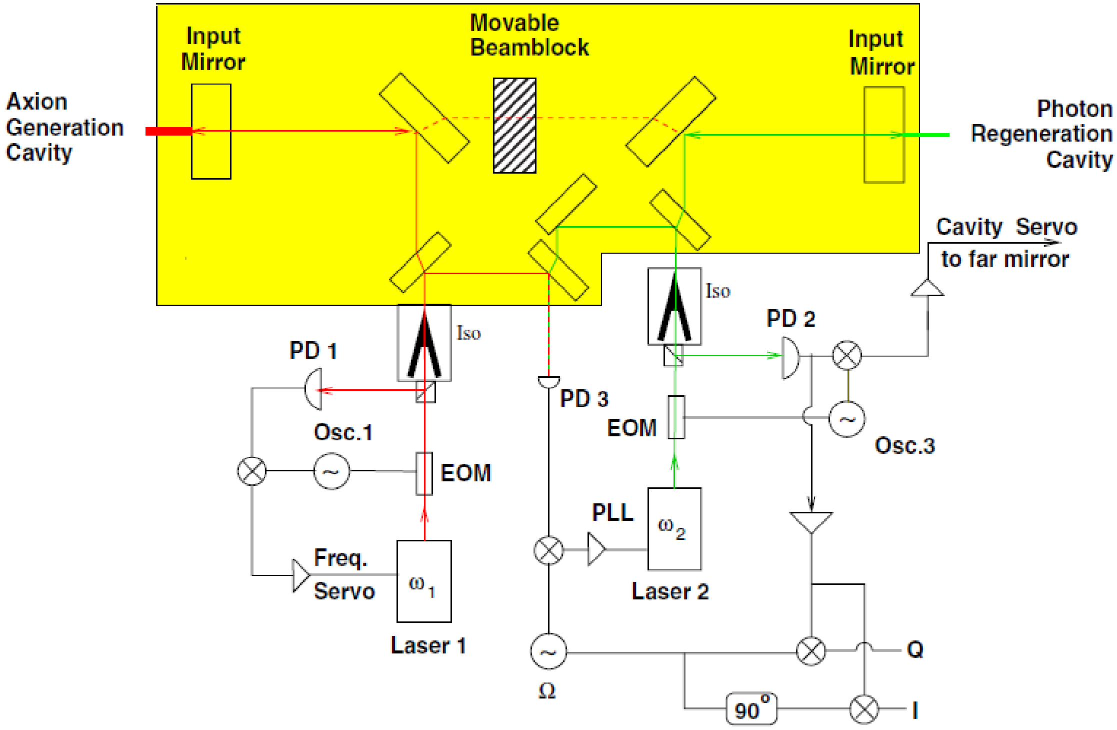
"Resonantly enhanced Axion-Photon Regeneration"
P. Sikivie, D.B. Tanner , Karl van Bibber. *Phys.Rev.Lett.98:172002,2007.*

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

A possible Scenario for ALPS II

Laser and resonators:

> There exist several ideas on how to set-up such a system:



"Detailed design of a resonantly-enhanced axion-photon regeneration experiment"
G. Mueller, P. Sikivie, D. B. Tanner and K. v.Bibber
10.1103/PhysRevD.80.072004

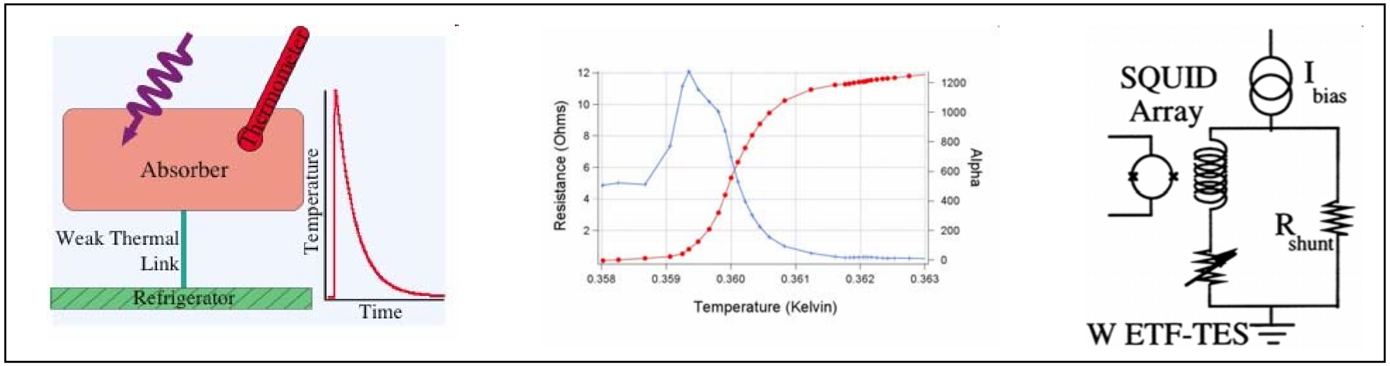
Use two lasers with offset in frequency to also allow for a heterodyne detection scheme.

An alternative is sketched in an internal ALPS note.

Possible Scenarios for future LSW Experiments at DESY

Detectors:

> Strive for a "background-free" single photon counter: Transition Edge Sensors



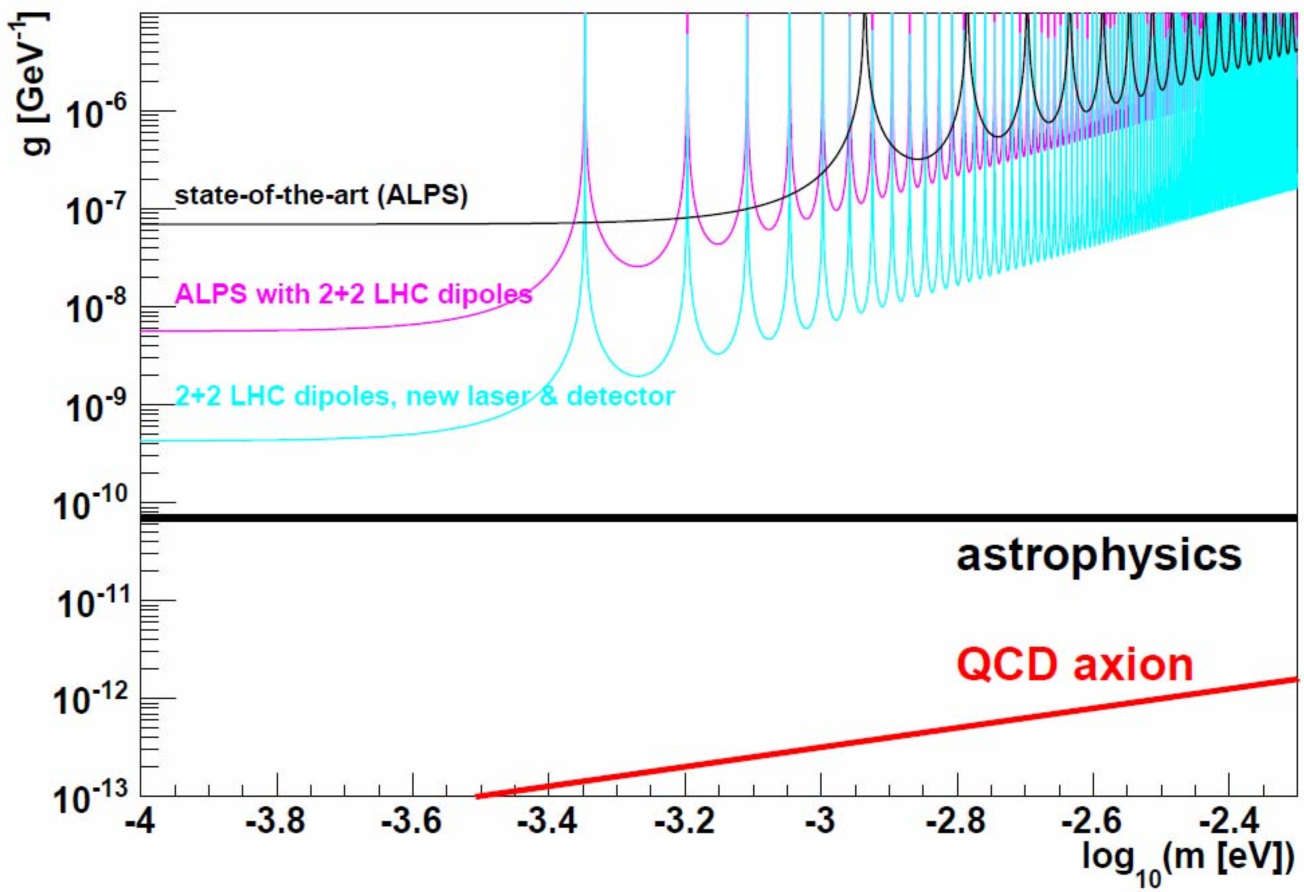
> Heterodyne detection: mix two signals and search for a Fourier component.

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

> A detailed trade-off study should start as soon as possible; the result may have influence on the locking scheme.

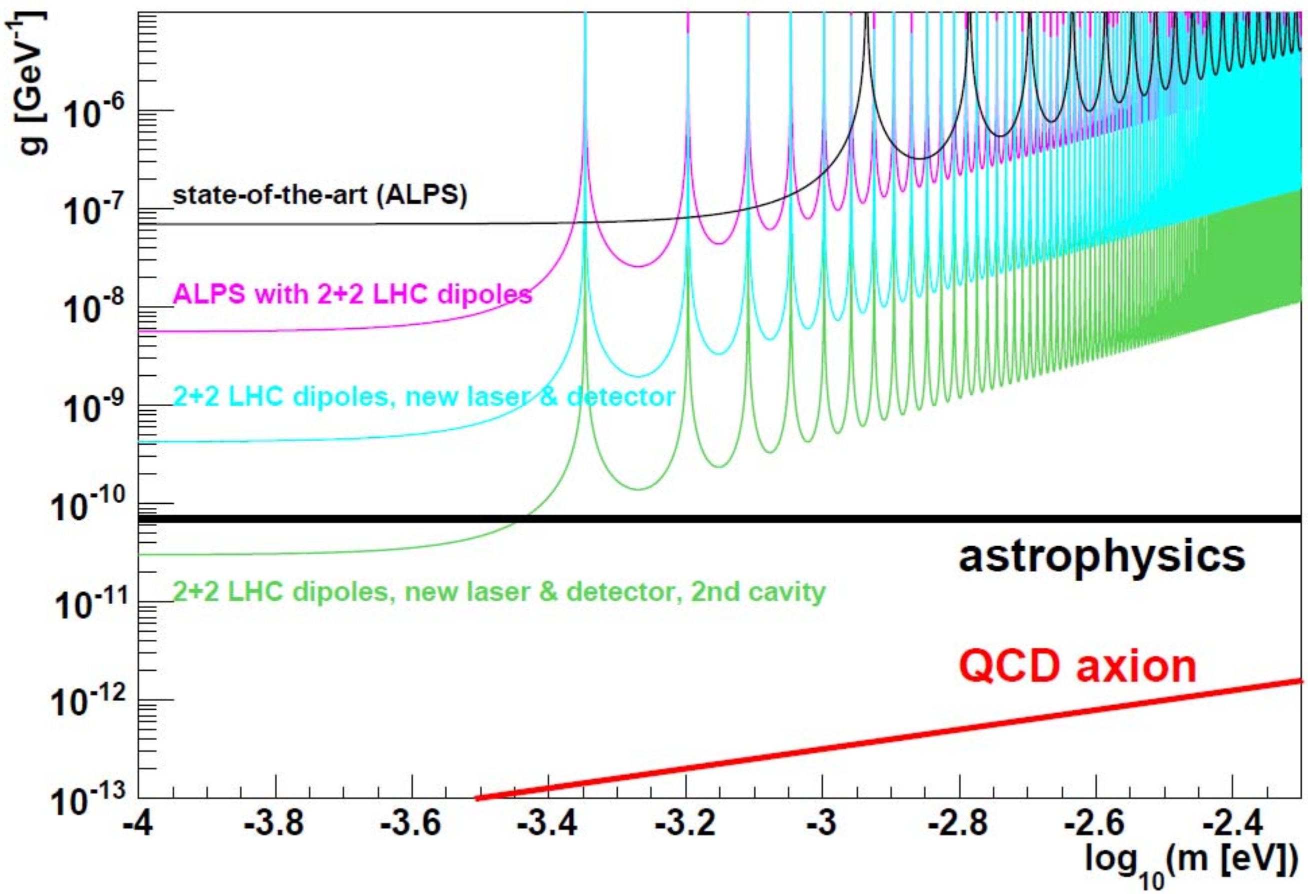
A possible Scenario for ALPS II

- Increase laser power from 1 kW to 150 kW, add single photon detector.



A possible Scenario for ALPS II

> Include a second resonator in the detector tube behind the wall.



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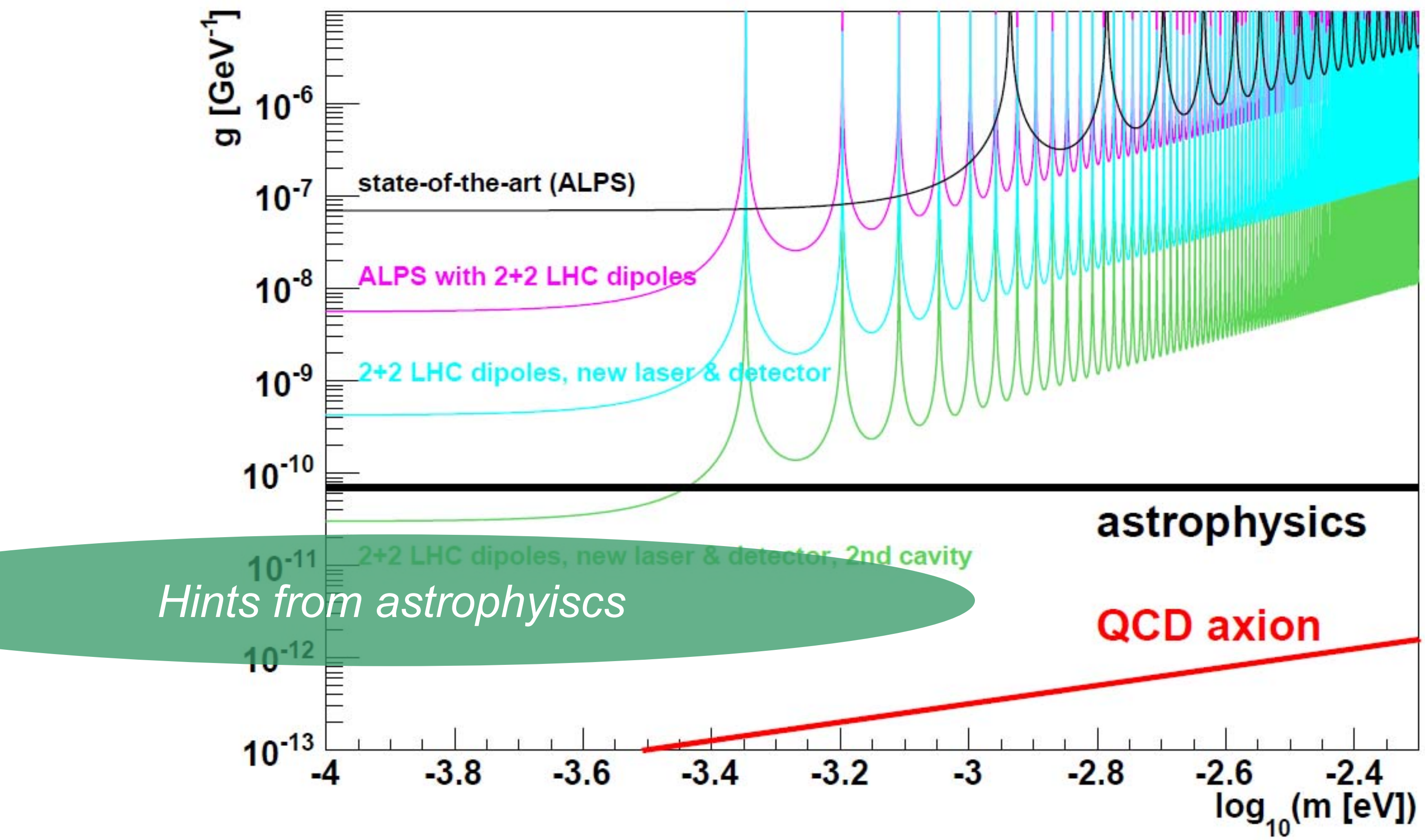
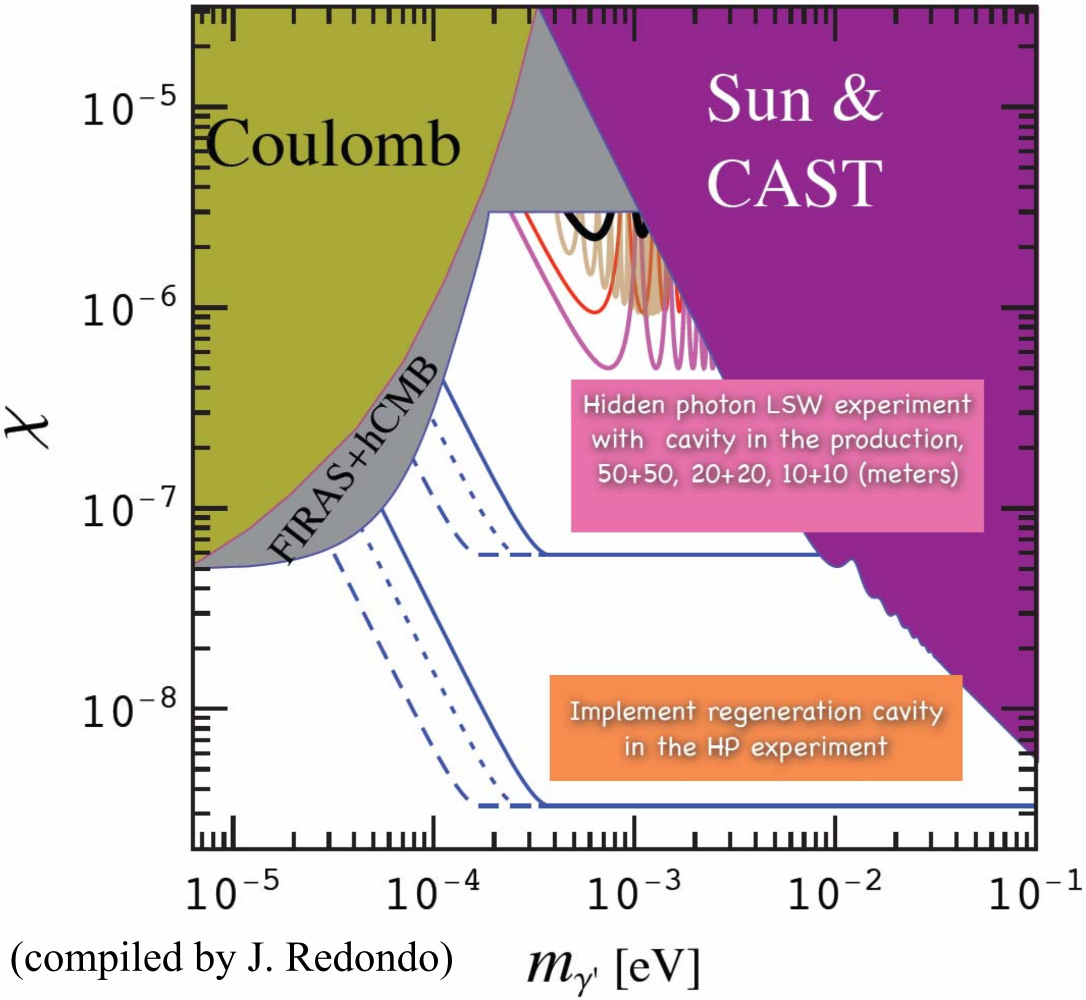
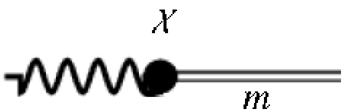


Without Magnets: searching for hidden Photons



(compiled by J. Redondo)



Only laboratory experiments searching for massive hidden sector γ´ might close the gap in the meV mass region!

No magnet needed, only long straight vacuum tubes!

Another rediscovered Area: GeV Dark Forces

Dark Forces Workshop

SEARCHES FOR NEW FORCES AT THE GeV-SCALE   SLAC NATIONAL ACCELERATOR LABORATORY

- Home
- Registration
- Program
- Organizers
- Participant List
- Accommodations
- General Information
- Travel and Directions
- Visa Information
- Contact

Credit: source images used courtesy of CERN *and* V. Springel et al./Millennium Simulation

Searches for New Forces at the GeV-scale

Date/Time: September 24th to 26th, 2009.
- Thu : from 8:30am to 6:00pm
- Fri : from 9:00am to 6:00pm
- Sat : from 9:00am to 5:00pm

Location
Building: 48 ROB A/B/C/D
SLAC National Accelerator Laboratory
Menlo Park, California

Theoretical models related to dark matter have proposed that there are long-range forces mediated by new gauge bosons with masses in the MeV to GeV range and very weak coupling to ordinary matter. The experimental constraints on the existence of these new gauge bosons are quite weak. This workshop will bring together theorists and experimentalists to stimulate progress in searching for these "dark forces" in three arenas:

1. new fixed-target experiments at electron and proton accelerators such as JLab, SLAC, and Fermilab;
2. searches at high-luminosity e+e- experiments, including BaBar, BELLE, CLEO-c, KLOE, and BES-III;
3. searches at the Tevatron experiments.

REGISTRATION

This meeting is free to registered participants. Registration is necessary to participate in the workshop.

» Register

ACCOMMODATIONS

Please reserve your room early at Stanford Guest House.

» More Information

SLAC National Accelerator Laboratory, Menlo Park, CA
Operated by Stanford University for the U.S. Dept. of Energy
Office of Science

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

Possible GeV Dark Force Experiments at DESY

- The DESY electron beams offer opportunities for competitive fixed target experiments.
- A first set-up at the DESY II transfer line to DORIS is being investigated.

Search for New Dark Gauge Forces
i.e. a New Test Beam for DESY

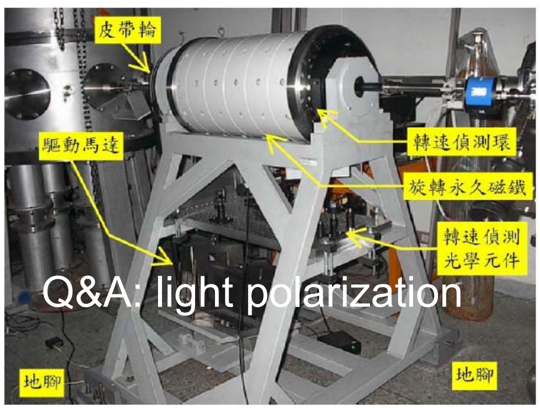
Sarah Andrea, Philip Bechtle, Heiko Ehrlichmann, Erika Garutti, Ingrid-Maria Gregor, Axel Lindner, Andreas Ringwald
DESY Hamburg, Notkestr. 85, D-22603 Hamburg, Germany

Draft of November 16, 2009

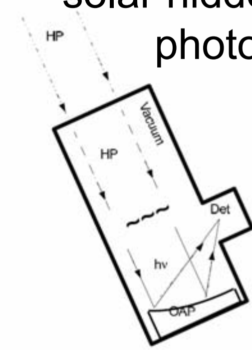
Summary

- 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.



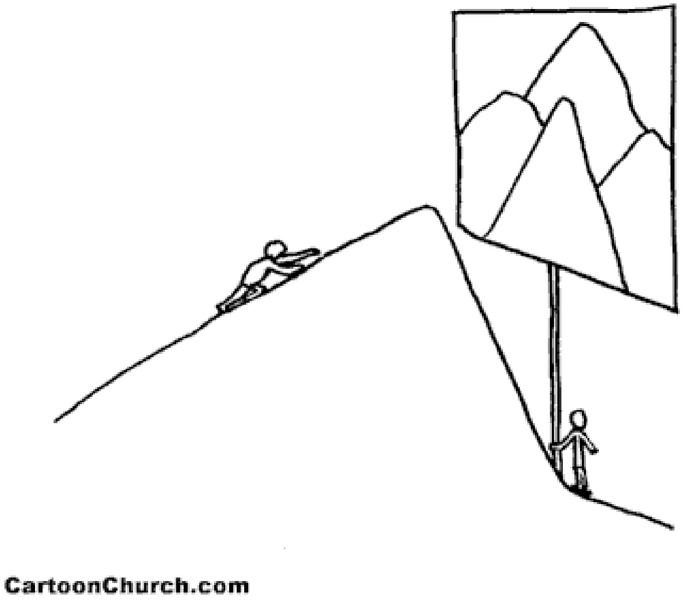
SHIPS:
DESY / Uni HH
proposal for
solar hidden
photons



> We should close these gaps of knowledge!

It might look challenging …

… but surprises might be close!



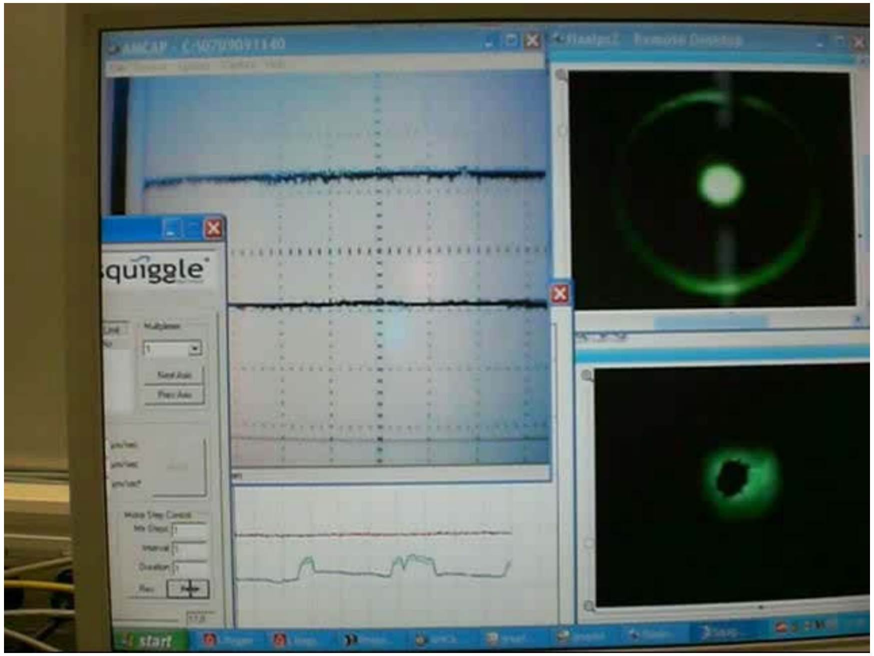
Thanks to the ALPS Collaboration!

Klaus Ehret[a], Maik Frede[b], Samvel Ghazaryan[a], Matthias Hildebrandt[b], Ernst-Axel Knabbe[a], Dietmar Kracht[b], Axel Lindner[a], Jenny List[a], Tobias Meier[c], Niels Meyer[a], Dieter Notz[a], Javier Redondo[a], Andreas Ringwald[a], Günter Wiedemann[d], Benno Willke[c]

[a] *Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, D-22607 Hamburg, Germany*
[b] *Laser Zentrum Hannover e.V., Hollerithallee 8, D-30419 Hannover, Germany*
[c] *Max-Planck-Institute for Gravitational Physics, Albert-Einstein-Institute, and Institut für Gravitationsphysik, Leibniz Universität, Hannover, Callinstraße 38, D-30167 Hannover, Germany*
[d] *Hamburger Sternwarte, Gojenbergsweg 112, D-21029 Hamburg, Germany*

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)