Towards the ALPS-II Experiment

Status Report to the DESY PRC

A. Lindner, for the ALPS Collaboration

DESY, 28 April 2011

HELMHOLTZ ASSOCIATION

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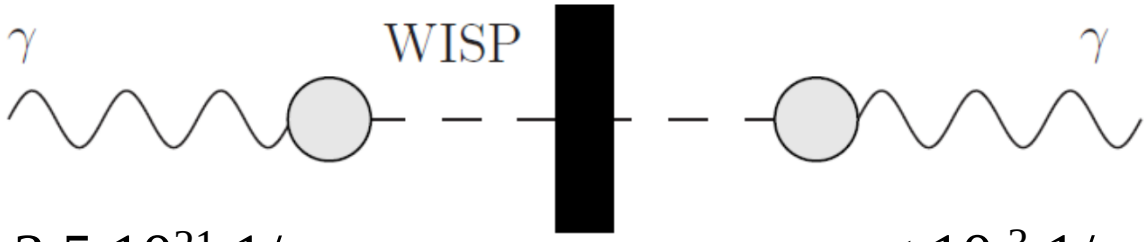
ALPS @ DESY in Hamburg

Reminder: ALPS-I Results

(PLB Vol. 689 (2010), 149, or http://arxiv.org/abs/1004.1313)

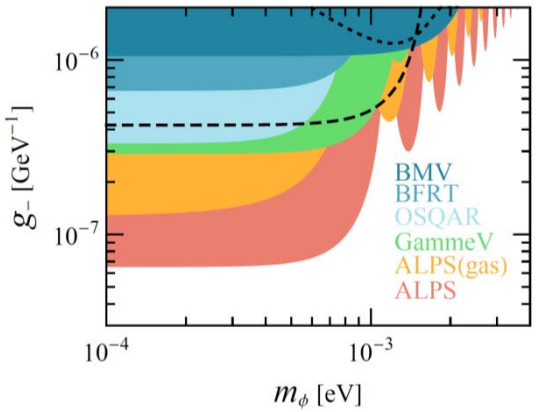
> Unfortunately, no light was shining through the wall!



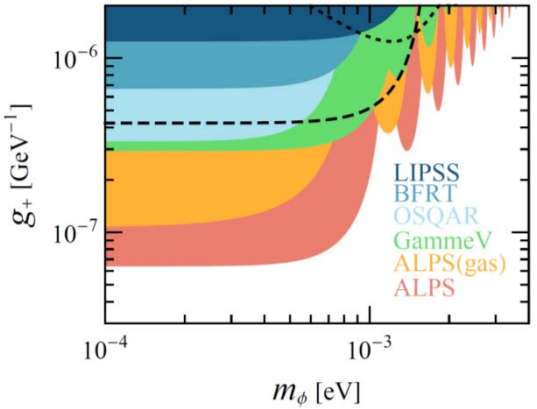
$3.5 \cdot 10^{21}$ 1/s $< 10^{-3}$ 1/s

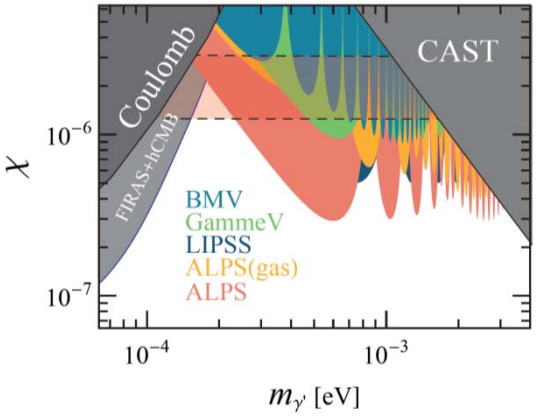
Reminder: ALPS-I Results

> ALPS is the most sensitive experiment for WISP searches in the laboratory.



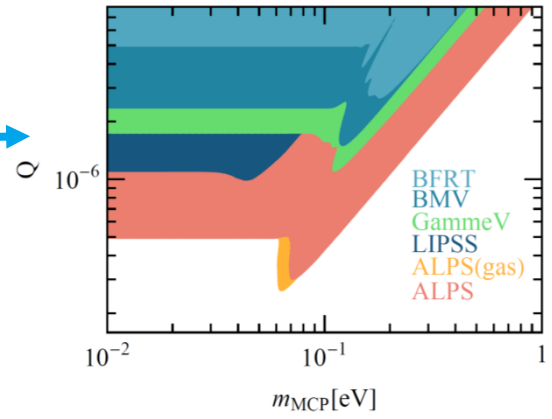
pseudoscalar and scalar axion-like particles





hidden sector photons and minicharged particles

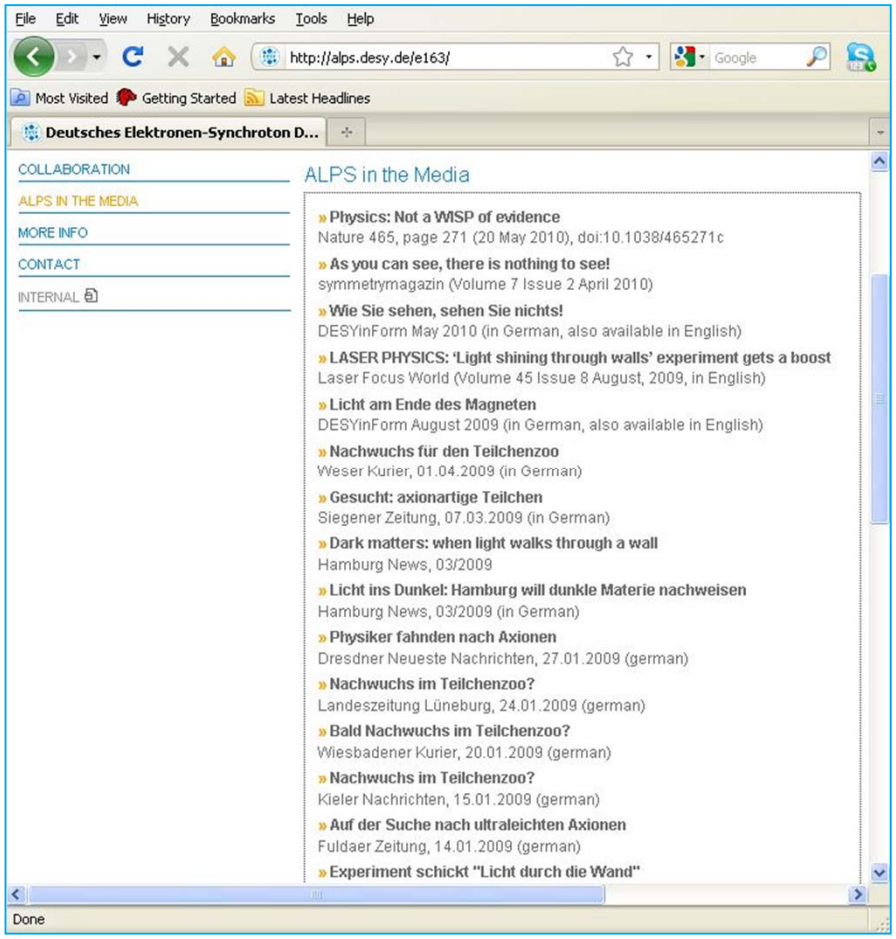
Filling a gap remaining from astrophysics and other experiments!

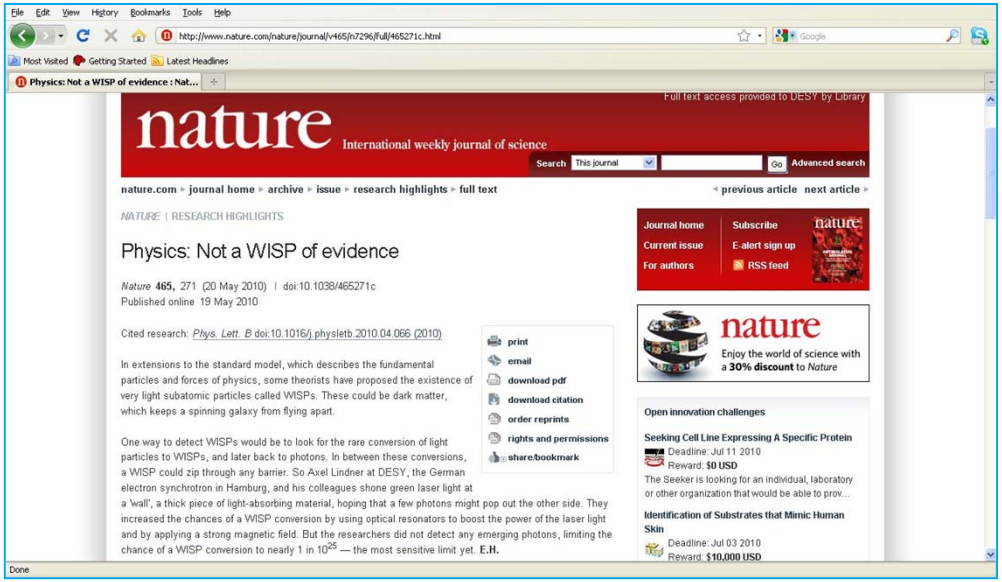


PLB 689 (2010), 149

Outreach (see also http://alps.desy.de)

Large interest in media, many invited talks, mentioned in *Nature.*





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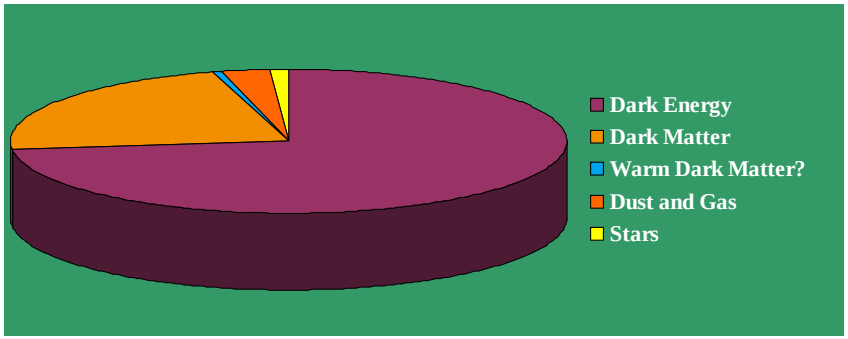
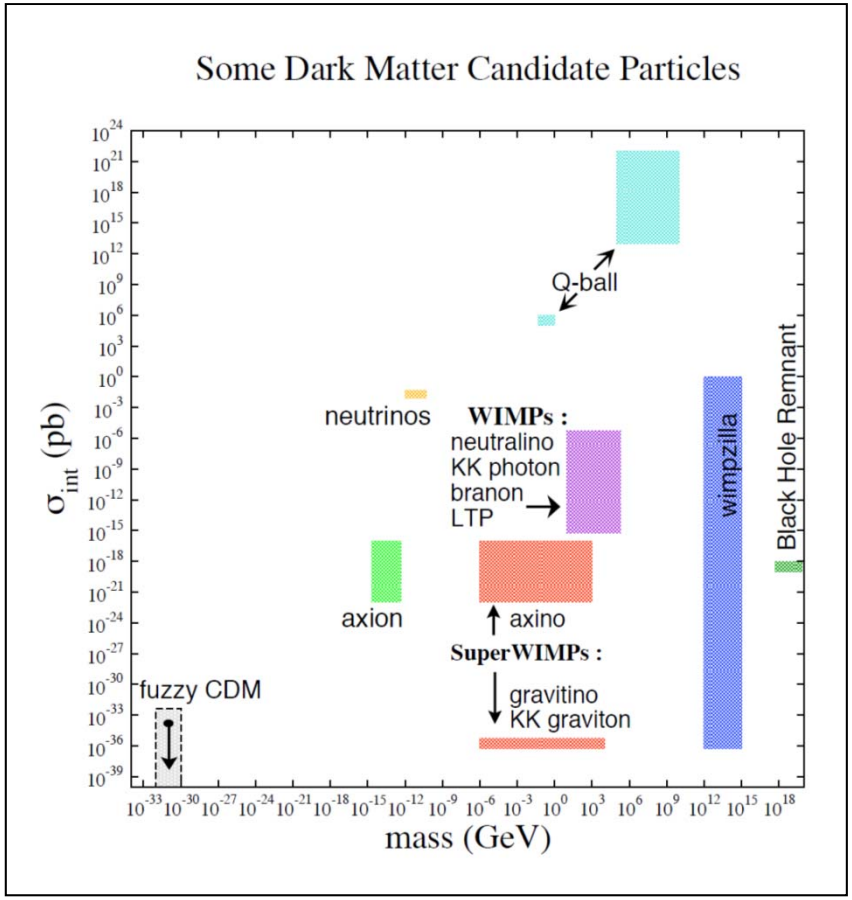
Motivation for further WISP Searches: the Universe

The Universe is essentially dark:





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

Dark Matter could be WISPy!

Motivation for further WISP Searches: the Universe

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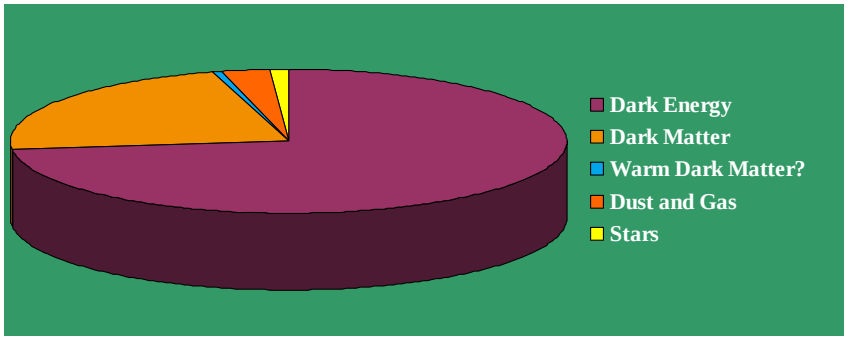

The cosmological constant problem, *S. Weinberg*, Rev. Mod. Phys. 61, 1–23 (1989)

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.

Laboratory constraints on chameleon dark energy and power-law fields

J. H. Steffen[1], A. Upadhye[2], A. Baumbaugh[1], A. S. Chou[1], P. O. Mazur[1], R. Tomlin[1], A. Weltman[3], and W. Wester[1]
[1]*Fermi National Accelerator Laboratory, PO Box 500, Batavia, IL 60510*
[2]*Kavli Institute for Cosmological Physics, University of Chicago, IL 60637*
[3]*Astrophysics, Cosmology and Gravity Centre, University of Cape Town, Rondebosch, Private Bag, 7700, South Africa*
(Dated: October 6, 2010)

Dark Energy could be WISPy!

Motivation for further WISP Searches: 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]
- 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]
- Signatures of a hidden cosmic microwave background
  J.Jaeckel, J. Redondo, A. Ringwald, Phys.Rev.Lett.101:131801,2008

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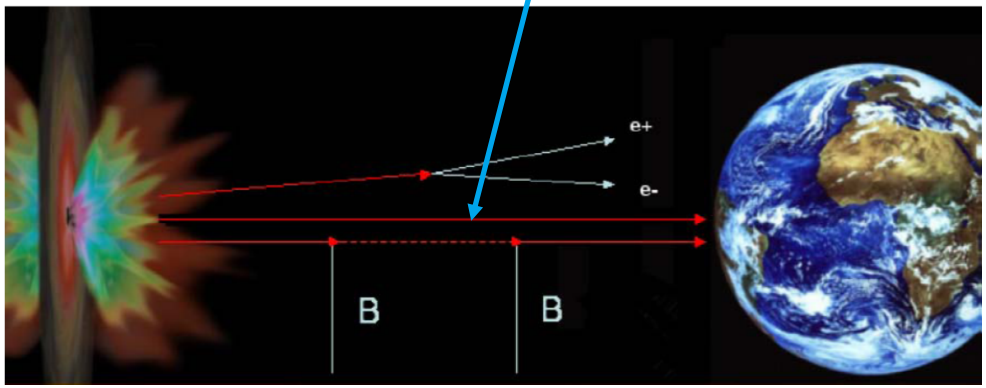
TeV photons should be absorbed by e^+e^- pair production due to interaction with the extragalactic background light (EBL):

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

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

TeV photons may “hide” as ALPs!

M. Roncadelli, presentation at the 4th Patras Workshop on Axions, WIMPs and WISPs, 2008

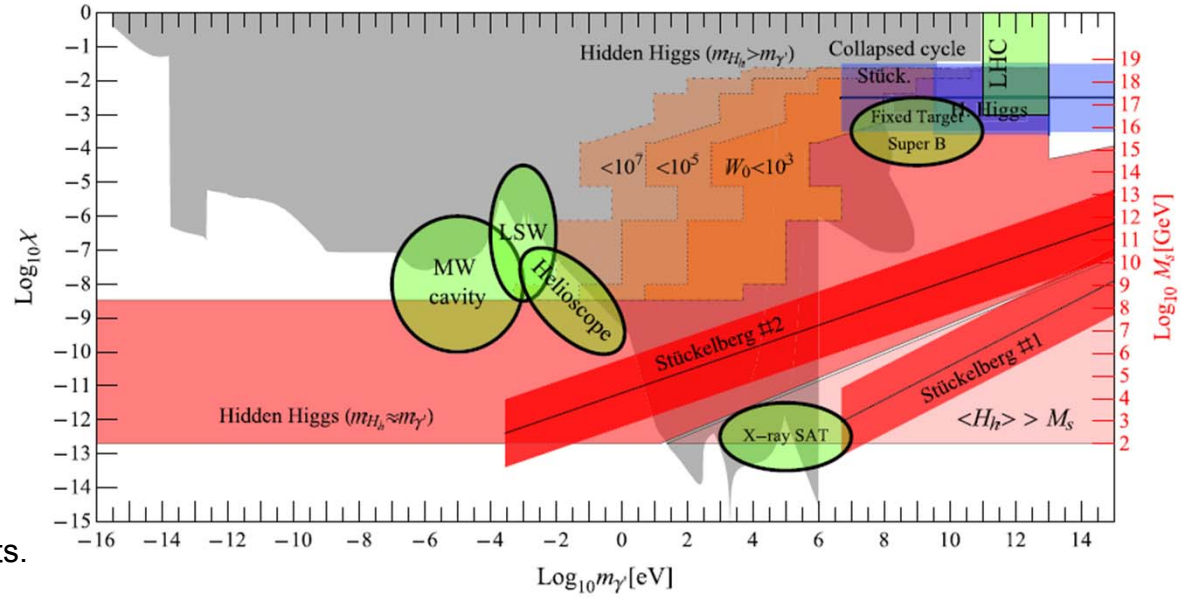


Motivation for further WISP Searches: Theory

- The CP conservation in QCD is best explained by an axion.
- A QCD axion in the mass region of 10^{-5} to 10^{-4} eV would be a “perfect” cold Dark Matter candidate.
- 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 10-33eV. Conversely the presence of such a plenitude of axions (an “axiverse") would be evidence for string theory, …
- Naturally Light Hidden Photons in LARGE Volume String Compactifications

  M. Goodsell, J. Jaeckel, J. Redondo and A. Ringwald, arXiv:0909.0515 [hep-ph], J HEP 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.



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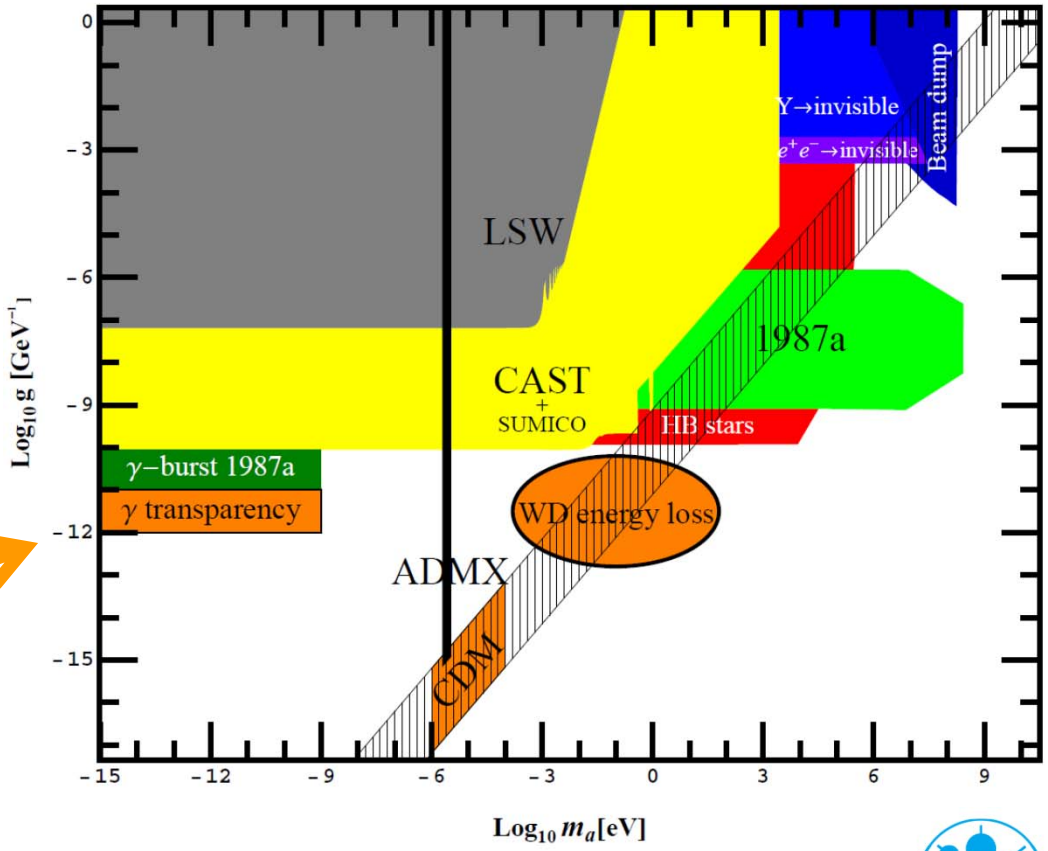
ALPS-I Summary and the ALPs / Axion Challenge

- Experience gathered with ALPS is a firm foundation 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.
- Infrastructure and large magnets provided by a lab like DESY are essential to accomplish experiments like ALPS.
- Significant efforts required to check indirect limits from and to compete with astrophysics!

We have to aim for this sensitivity!

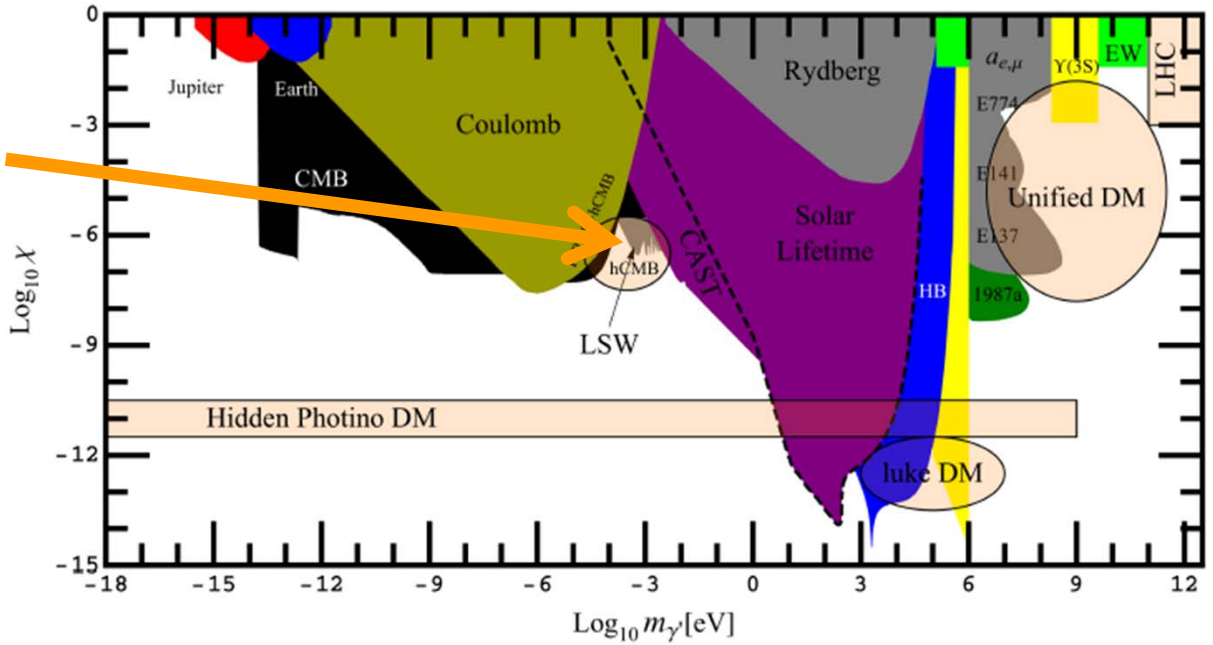


compiled by J. Jäckel and A. Ringwald

ALPS-I Summary and the “hidden Photon” Challenge

- In the near term experiment should strive for probing the “hidden CMB” interpretation of the neutrino number excess derived from CMB data.
- A drastic increase in sensitivity is required to probe for hidden photino Dark Matter. This will not be possible in the near term future.

We have to probe here!



compiled by J. Jäckel and A. Ringwald

WISPs Searches in the Lab worldwide I

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

Experiment	ω	P_g	β_g	Magnets
ALPS (DESY) [61, 62]	2.33 eV	4 W	300	$B_g = B_r = 5$ T $L_g = L_r = 4.21$ m
BFRT (Brookhaven) [64, 65]	2.47 eV	3 W	100	$B_g = B_r = 3.7$ T $L_g = L_r = 4.4$ m
BMV (LULI) [66, 67]	1.17 eV	8×10^{21} $\frac{\gamma}{\text{pulse}}$ (14 pulses)	1	$B_g = B_r = 12.3$ T $L_g = L_r = 0.4$ m
GammeV (Fermilab) [68]	2.33 eV	4×10^{17} $\frac{\gamma}{\text{pulse}}$ (3600 pulses)	1	$B_g = B_r = 5$ T $L_g = L_r = 3$ m
LIPSS (JLab) [69, 70]	1.03 eV	180 W	1	$B_g = B_r = 1.7$ T $L_g = L_r = 1$ m
OSQAR (CERN) [71, 72]	2.5 eV	15 W	1	$B_g = B_r = 9$ T $L_g = L_r = 7$ m
BMV (ESRF) [73]	50/90 keV	10/0.5 mW	1	$B_g = B_r = 3$ T $L_g = 1.5, L_r \sim 1$ m

Table 1. Some experimental parameters of the past and current generation of LSW experiments.

Light shining through walls,
Javier Redondo, Andreas Ringwald,
arXiv:1011.3741v1 [hep-ph]

DESY

WISPs Searches in the Lab worldwide II

> CERN: OSQAR

- Results announced for the end of 2010, but nothing communicated yet.
  B·L(OSQAR) = 4 x B·L (ALPS); factor 4 in B·L <=> factor 256 in laser power!

> FNAL: GammeV, CHASE

- At present concentrating on holographic noise,
  strong push with planned shutdown of TEVATRON?

> KEK: plans for different experiments exploiting high power lasers

- In the planning phase, likely to be delayed.

> Korea: plans for a dedicated “axion search laboratory”

- Details of the activities are not fixed yet.

> DESY: ALPS-II

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DESY

The ALPS Collaboration

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 /neoLASE
- Hamburger Sternwarte and Hamburg University (new)

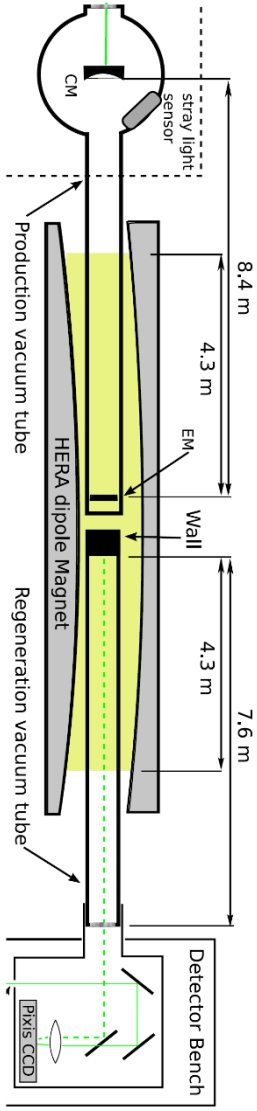
Four PhD students fully committed to ALPS started in autumn 2010!

Three main ALPS-I Components

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

> Strong magnet:
One HERA dipole: 5 T, superconducting

> Sensitive detector:
CCD



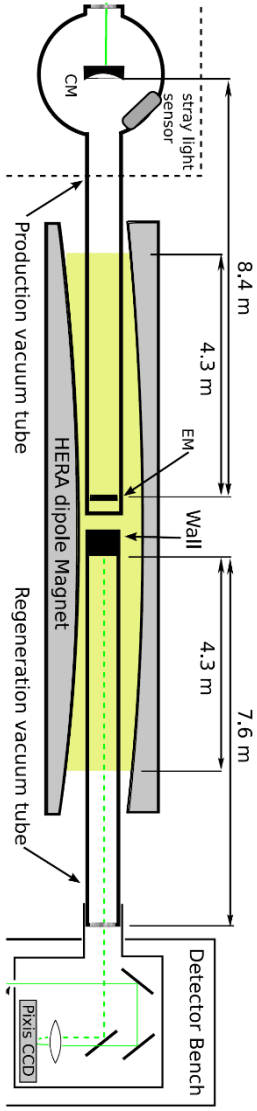
Tubes:
- diameter: 34 mm
- clear aperture: 14 mm

An ALPS-II Scenario

> Powerful laser:
optical cavity to recycle laser power
(high quality laser beam)
ALPS-II: improve power!

> Strong magnet:
One HERA dipole: 5 T, superconducting
ALPS-II: switch to magnet strings!

> Sensitive detector:
CCD
ALPS-II: regeneration cavity and
TES detector!



Tubes:
- diameter: 34 mm
- clear aperture: 14 mm

ALPS-II: Straighten magnets!

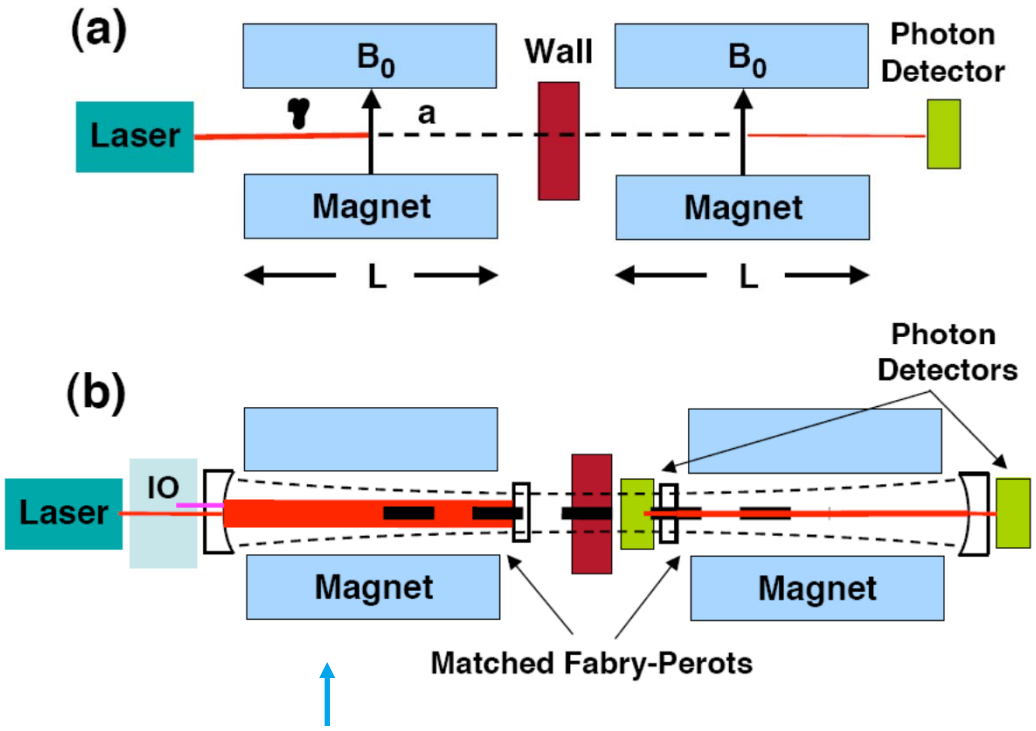
ALPS-II in Numbers (realistic, but wishful …)

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

ALPS-II: Regeneration Cavity

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.*

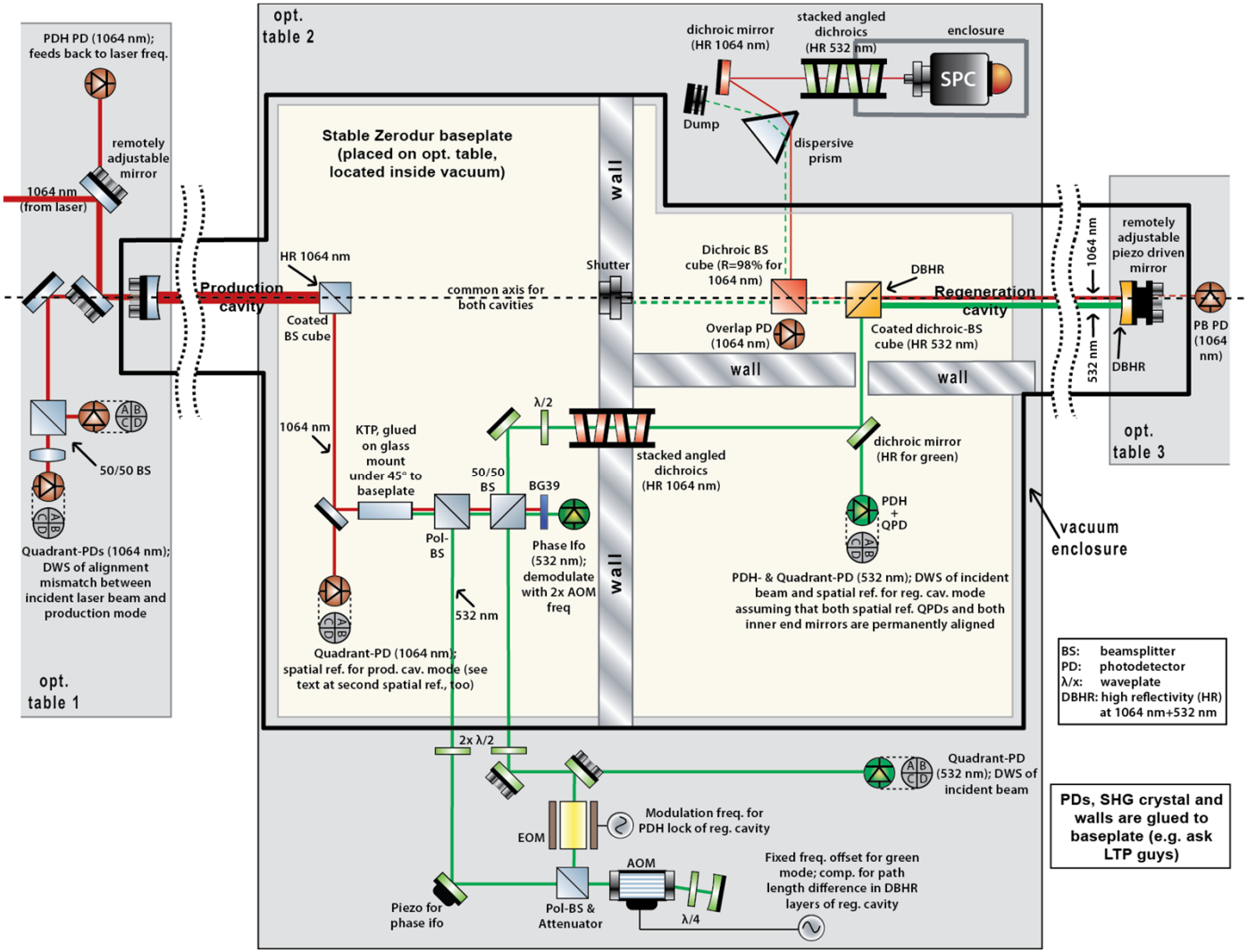
(also F. Hoogeveen, T. Ziegenhagen, DESY-90-165, Nucl.Phys.B358)

ALPS-II: optical System

Sketch of the optical system:

On paper a working scenario exists. Alternatives have been worked our also.

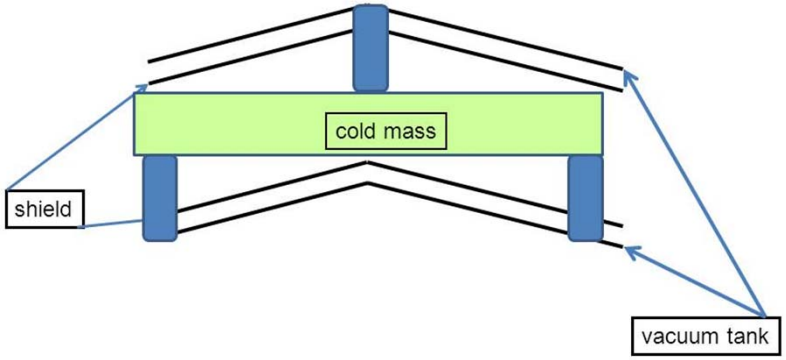
Crucial to decide on the next steps is the measurement of the amount of down-converted light from the green light used to lock the regeneration cavity.

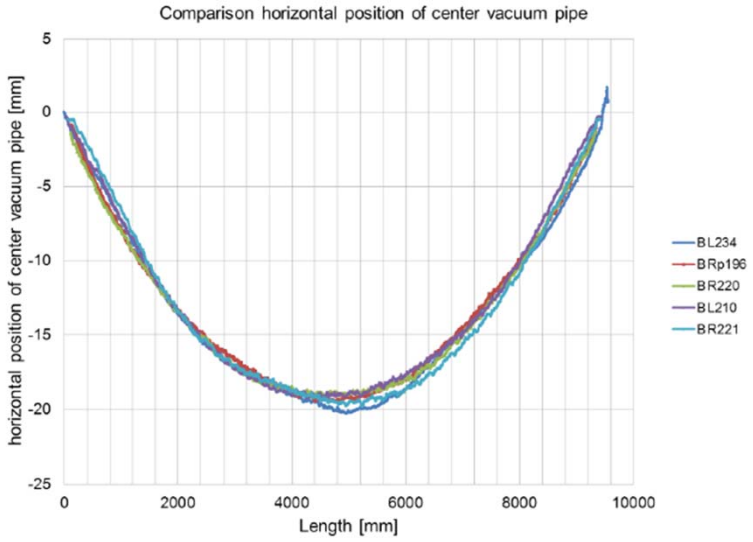


ALPS-II: HERA Dipoles

> Prepare for attempt to straigthen a dipole to increase the aperture.

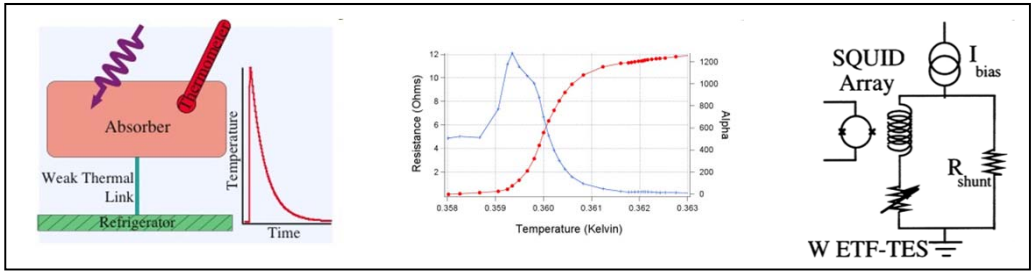
Third step: force ends of cold mass towards the center by ~8 mm and fix it by appropriate structures





ALPS-II: Tansition Edge Sensor to count 1064 nm Photons

> Principle:



> Aims:

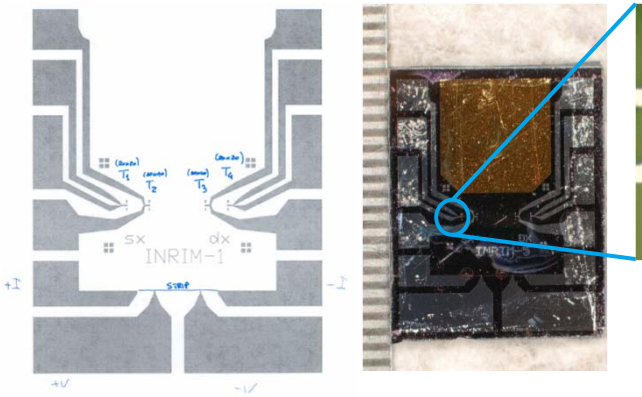
- Determination of background counts (only an upper limits of 10^{-3} 1/s are published)
- Energy resolution for single photons
- Efficient guiding of light onto the TES

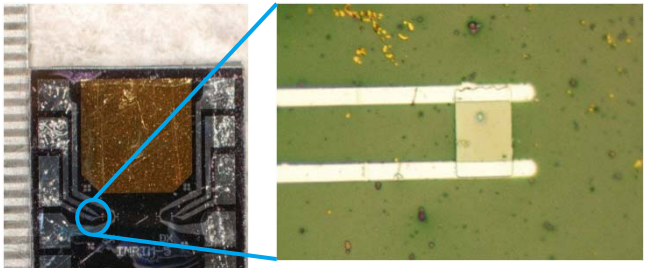
> A dedicated international team:

DESY, UHH, PTB, INFN, Università degli Studi di Trieste, UNICAM Università di Camerino 1336, Università degli Studi di Genova, INRiM Istituto Nazionale di Ricerca Metrologica, NIST National Institute of Standards and Technology (new)

ALPS-II: Tansition Edge Sensor to count 1064 nm Photons

> Our first TES from INRIM:



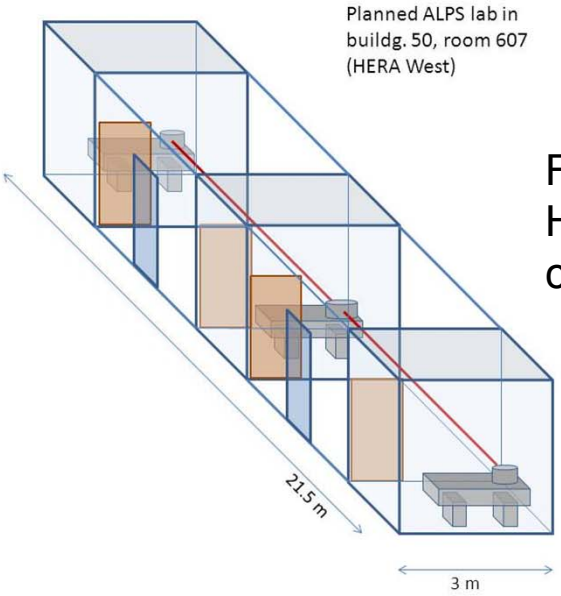


sensor area: 20µm x 20µm

> We hope for first experience and results in summer this year:

Work packages	Tasks	Location (Responsible)	Week beginning -> 25-Apr	2-May	9-May	16-May	23-May	30-May	6-Jun	13-Jun	20-Jun	27-Jun
TES preparation												
	TES baseplate design and machining	TS (Marin, Giovanni)	X	X	X							
	TES bonding	TS (Giovanni, Sasha)		X	X	X						
Cryostat preparation												
	Electrical feedtrough	TS (Marin, Giovanni and machine shop)	X	X	X							
	Otical fiber feedtrough	TS (Marin, Giovanni and machine shop)	X	X	X							
	Cold finger design and machining	Camerino (Riccardo and machine shop)		X	X	X						
	TES-SQUID assembly insertion into cryostat	Camerino (Riccardo)					X	X				
Optics												
	Fiber-TES optical coupling	Camerino (Marco, Jan)					X	X				
	Thermal tests on fiber	Camerino (Marco, Jan)					X	X				
Test measurements												
	Cooling tests	Camerino (Riccardo, Jan)							X	X	X	
	SQUID characterization	Camerino (Jan, Marin, Riccardo)								X	X	
	Transition curve measurements	Camerino (Jan, Marin, Riccardo)									X	X
	TES characterization	Camerino (Jan, Marin, Riccardo)									X	X
	Photon counting and background	Camerino (Jan, Marin, Riccardo)									X	X

ALPS-II: a new Laser Laboratory in HERA-Hall West



Former klystron hall in HERA-West, area cleaned and prepared.

Test of different supports for optical tables with seismic measurements.

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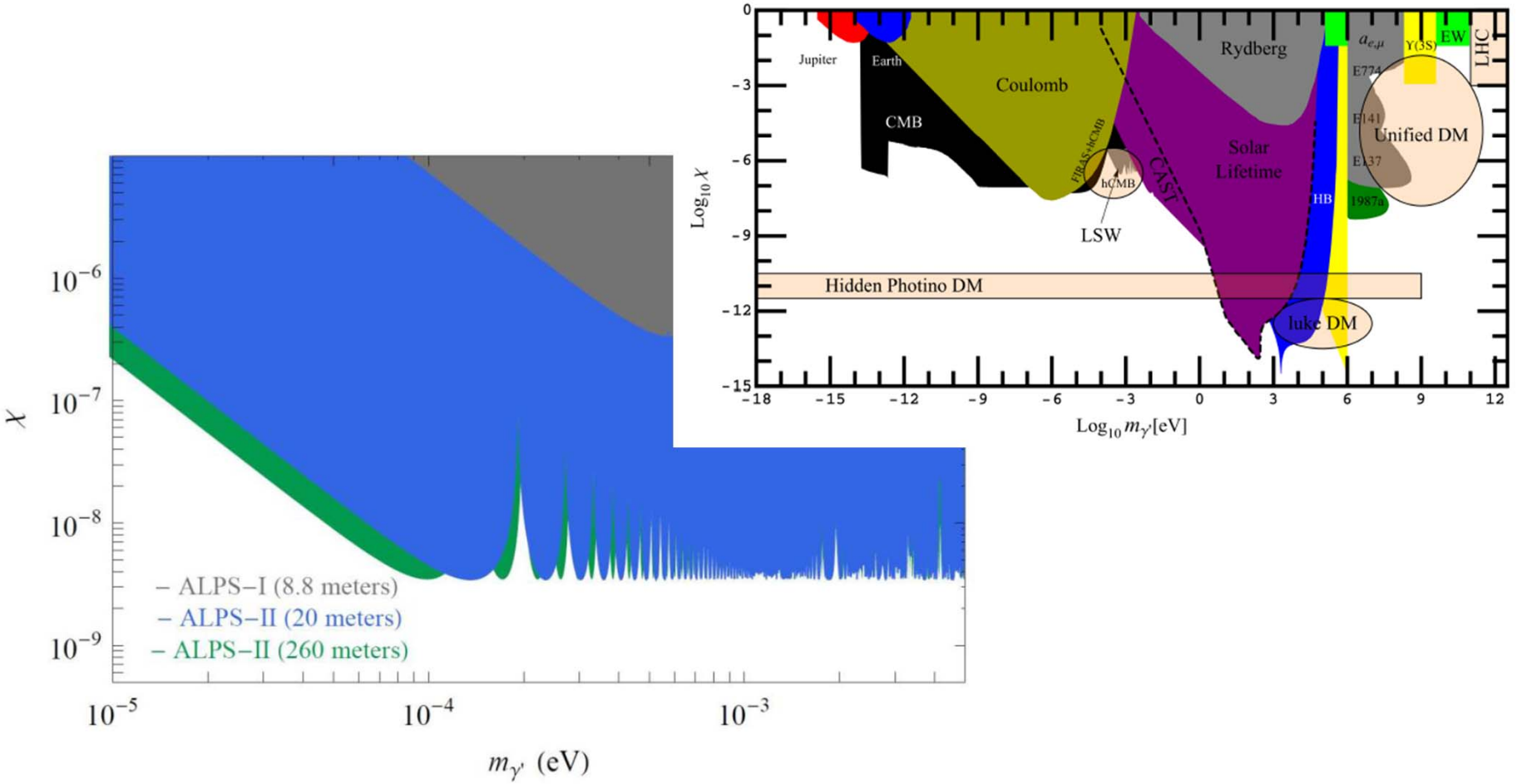
ALPS-II: Timeline

- Step 0 (spring 2012):
  Preparation of an ALPS-II TDR
- Step 1 (end of 2012):
  Set-up of hidden photon search with two 10m long vacuum tubes in the new laser laboratory in HERA-West.
  Magnets are not required here!
- Step 2 (end of 2014):
  Search for hidden photons with two 100m long vacuum tubes in the HERA tunnel (using the proton vacuum tube).
- Step 3 (2017):
  Search for axion-like particles in the HERA tunnel with two strings of HERA dipole magnets.
  - 4x4 dipoles
  - 12x12 straightened dipoles

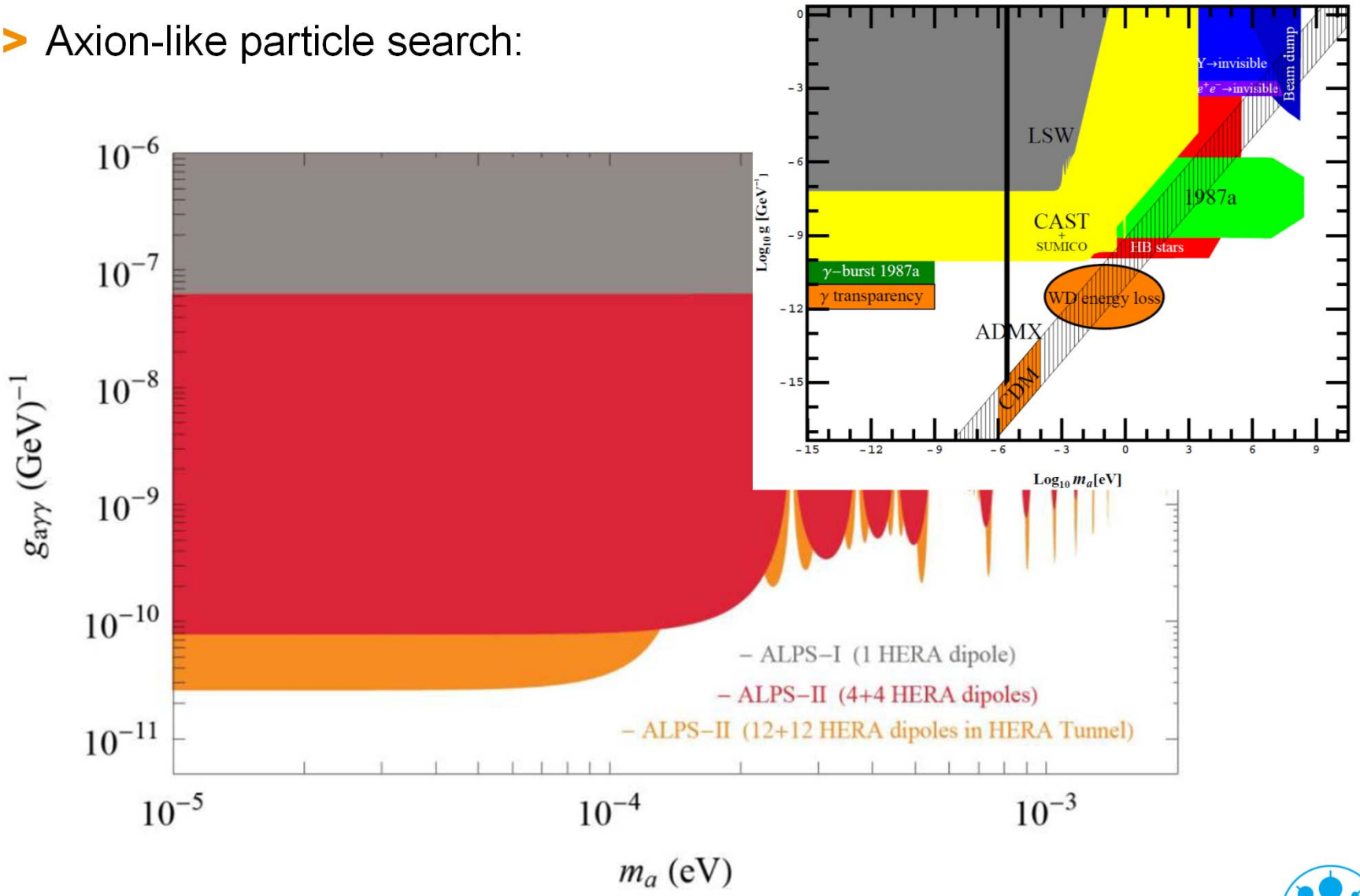
The ALPS-II Potential

> Hidden photon search (no magnets required):



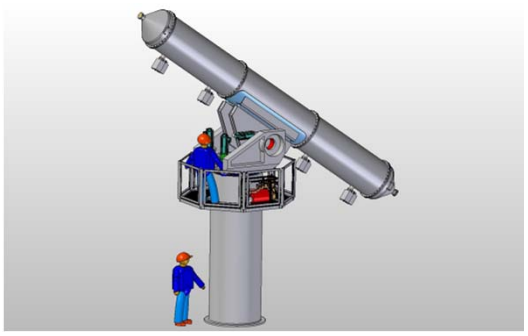
The ALPS-II Potential

- Axion-like particle search:



Summary

- ALPS-II has the potential to reach new horizons in WISP searches
  - Hidden photons: probe the hCMB prediction.
  - Axion-like particles:
    check indirect limits from astrophysics in the laboratory, touch regions of interest given by astrophysics.
- ALPS-II could be a nucleus at DESY for more WISP searches
  - SHIPS at Bergedorf / DESY



  - Discussions with other groups (CERN, Italy, Yale) on common projects.
- The ALPS activities trigger contacts to new scientific communities
  - (laser, gravitational waves, astronomy, optical detectors, quantum optics …)

ALPS-II @ DESY

… standing on the shoulders of a giant …

> ALPS-II (would like to) profit from

- the treasury of HERA magnets,
- the knowledge in cryogenics,
- the expertise in vacuum technology,
- the unique infrastructure (like long straight sections in the HERA tunnel),
- the know-how in detector technology,
- the world-leading position in theory,

> and could give

- new background-free optical photon detectors,
- 10-100 mK cryogenics,
- laser expertise,
- **break-through physics results!**

Invitation to the 7th Patras Workshop

http://axion-wimp.desy.de/