Searches for New Light Weakly Coupled Particles around DESY

Intensity Frontier Workshop
IF5: New Light Weakly Coupled Particles

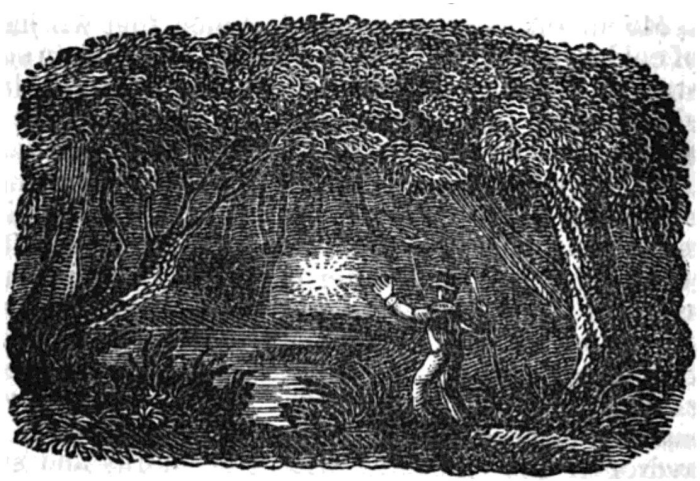
Argonne National Laboratory
25-27 April 2013

Axel Lindner, DESY

HELMHOLTZ ASSOCIATION

DESY

Directly looking for Weakly Interacting Slim Particles



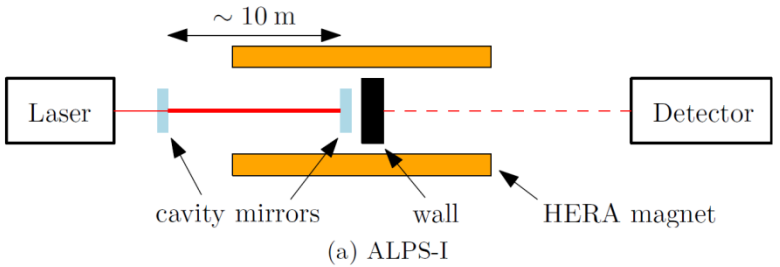
Mudie, *A Popular Guide to the Observation of Nature* (1836, p.144).
http://books.google.de/books?id=kdknAAAAMAAJ&pg=PP1#v=onepage&q&f=false

- Three kinds of WISP searches
- ALPS-II (purely laboratory search)
- TSHIPS (helioscope)
- WISPDMX and a “dish” vision (haloscopes)
- Summary

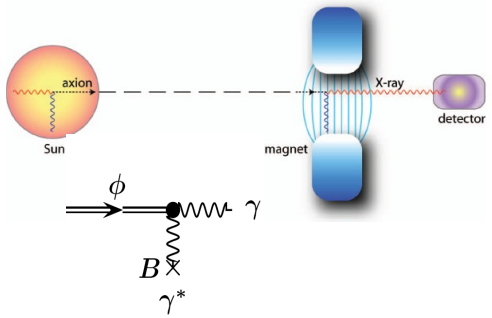
Three kinds of WISP searches

Weakly Interacting Slim Particles (WISPs) are searched for by

- Purely laboratory experiments ("light-shining-through-walls") optical photons,



- Helioscopes (WISPs emitted by the sun), X-rays,



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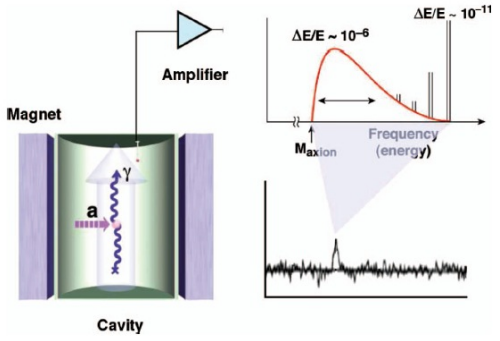

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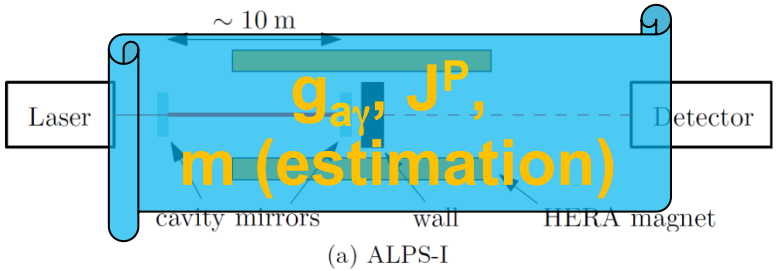

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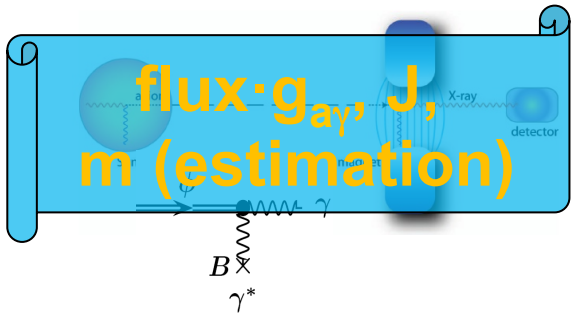

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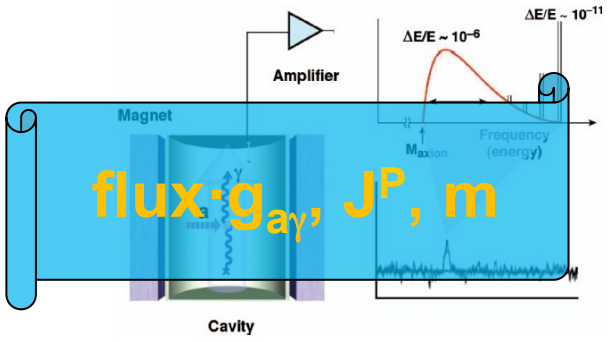

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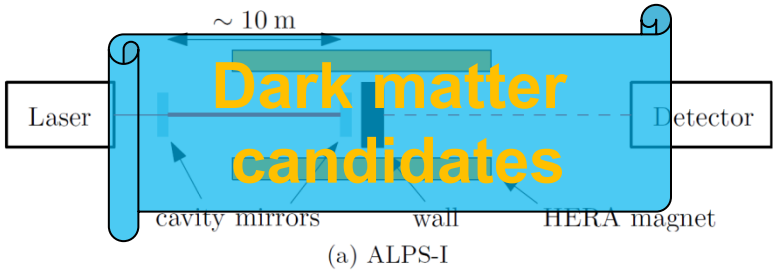

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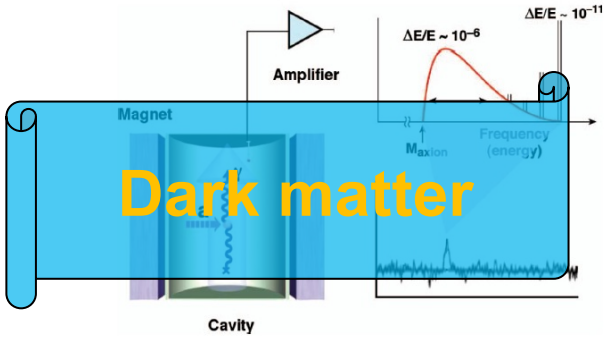

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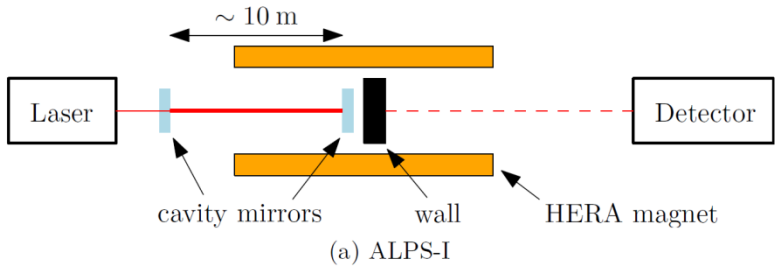

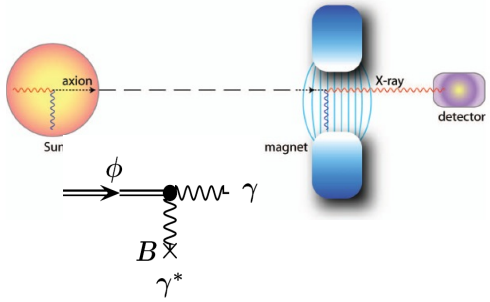

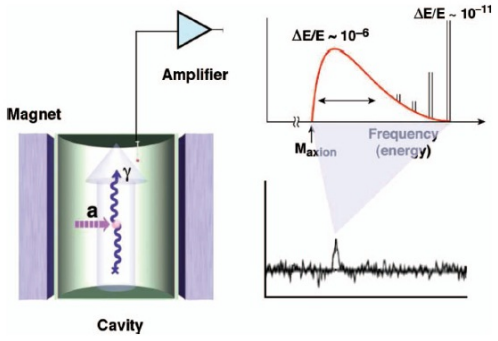

WISP flux

Three kinds of WISP searches

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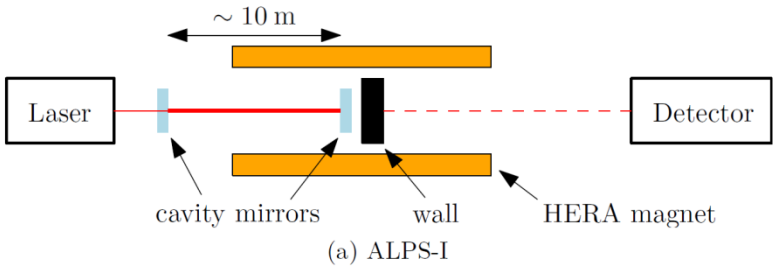

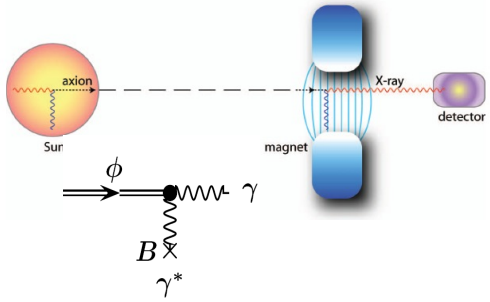

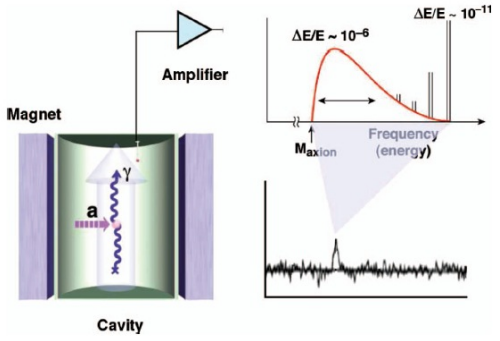

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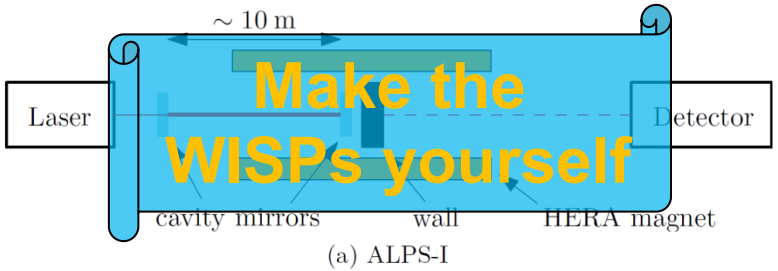

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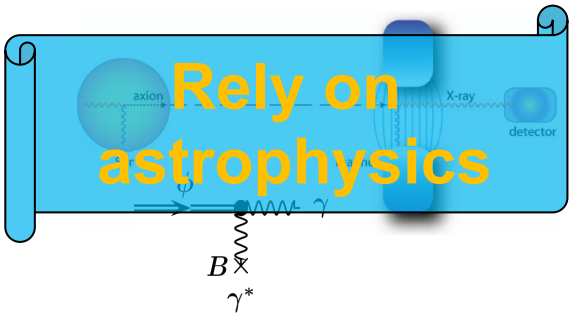

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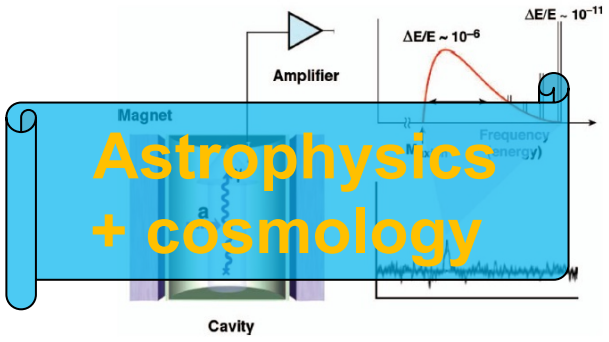

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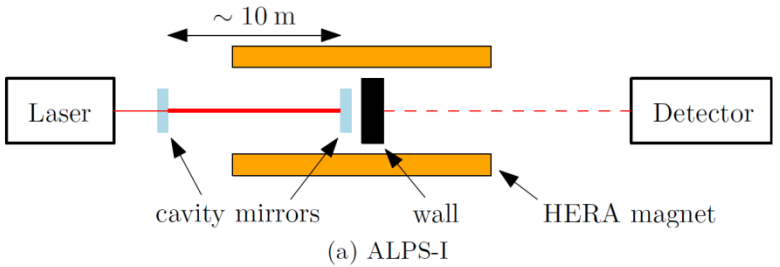

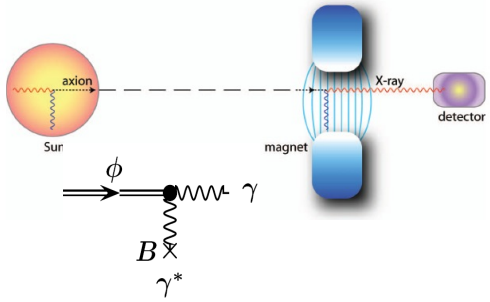

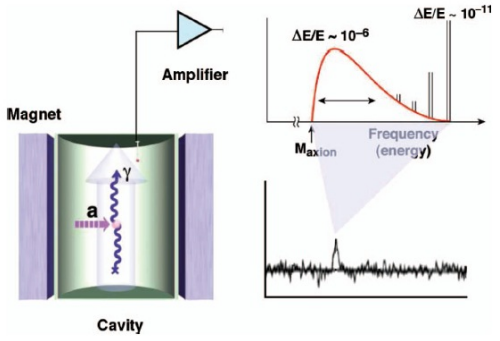

Theoretical uncertainty

WISP experiments worldwide

An incomplete selection of (mostly) small-scale experiments:

Experiment	Type	Location	Status
ALPS-II	Laboratory experiments, light-shining-through-a-wall	DESY	construction
CERN microwave cavity experiment		CERN	running
OSQAR		CERN	running
REAPR		FNAL	proposed
CAST	Helioscopes	CERN	running
IAXO		?	proposed
SUMICO		Tokyo	running
TSHIPS		Hamburg	started
ADMX	Haloscope	Seattle, NH	running
WISPDMX		DESY in HH	studies

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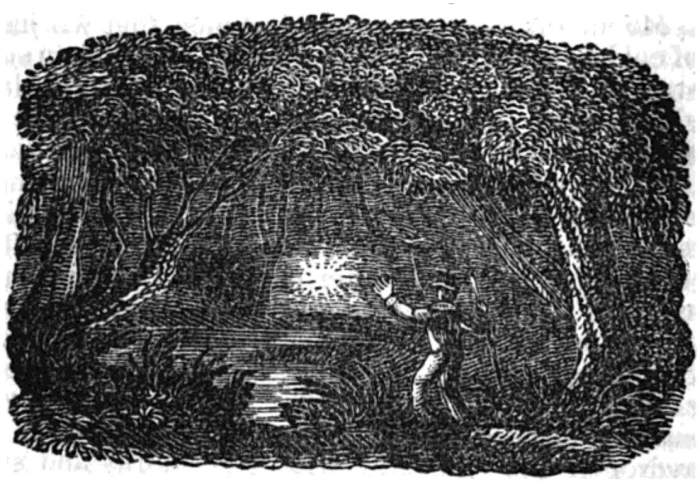

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Prospects for ALPS-II @ DESY

- Laser with optical cavity to recycle laser power, switch from 532 nm to 1064 nm, increase effective power from 1 to 150 kW.

- Magnet: upgrade to 10+10 straightened HERA dipoles instead of ½+½ used for ALPS-I.

- Regeneration cavity to increase WISP-photon conversions, single photon counter (superconducting transition edge sensor?).

All set up in a clean environment!

The ALPS-II reach

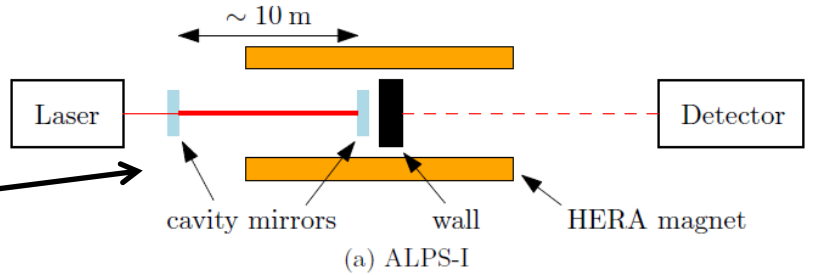
Parameter	Scaling	ALPS-I	ALPS-IIc	Sens. gain
Effective laser power P_{laser}	$g_{a\gamma} \propto P_{\mathrm{laser}}^{-1/4}$	1 kW	150 kW	3.5
Rel. photon number flux n_γ	$g_{a\gamma} \propto n_\gamma^{-1/4}$	1 (532 nm)	2 (1064 nm)	1.2
Power built up in RC P_{RC}	$g_{a\gamma} \propto P_{reg}^{-1/4}$	1	40,000	14
BL (before& after the wall)	$g_{a\gamma} \propto (BL)^{-1}$	22 Tm	468 Tm	21
Detector efficiency QE	$g_{a\gamma} \propto QE^{-1/4}$	0.9	0.75	0.96
Detector noise DC	$g_{a\gamma} \propto DC^{1/8}$	$0.0018\,\mathrm{s}^{-1}$	$0.000001\,\mathrm{s}^{-1}$	2.6
Combined improvements				3082

Three orders of magnitude gain in ALP coupling and two orders of magnitude in HP mixing!

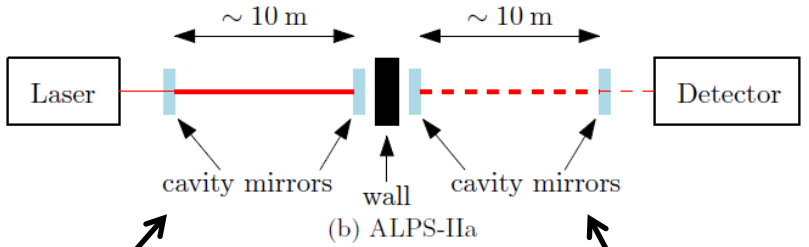
DESY

ALPS-II essentials: laser & optics

ALPS-I:
basis of success was the optical resonator in front of the wall.



> **ALPS-IIa**



Optical resonator to increase effective light flux by recycling the laser power

Optical resonator to increase the conversion probability

WISP→γ

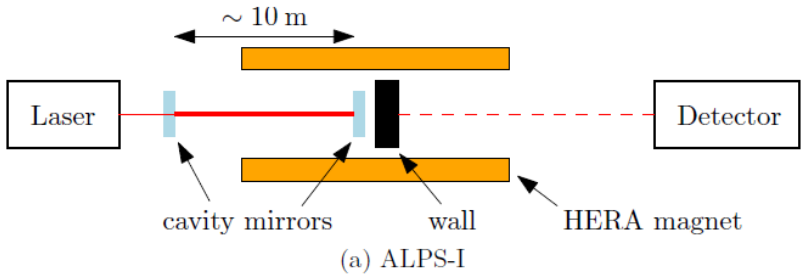
ALPS-II will be realized in stages

ALPS-I

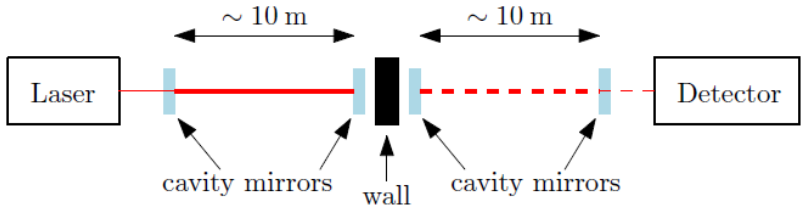
> ALPS-IIa

> ALPS-IIb

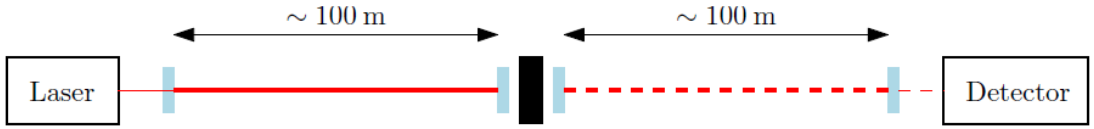
> ALPS-IIc



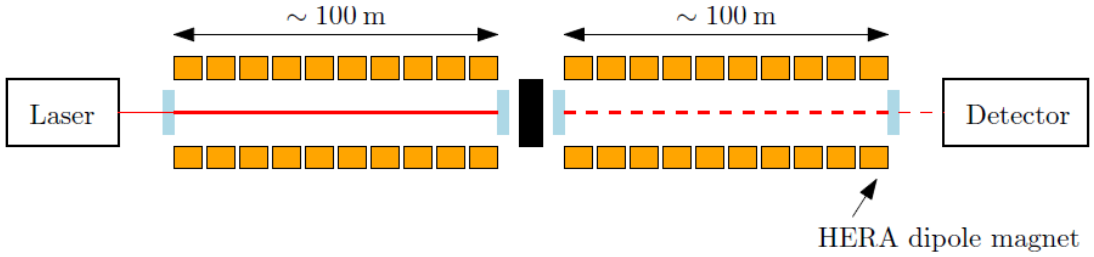
(a) ALPS-I



(b) ALPS-IIa



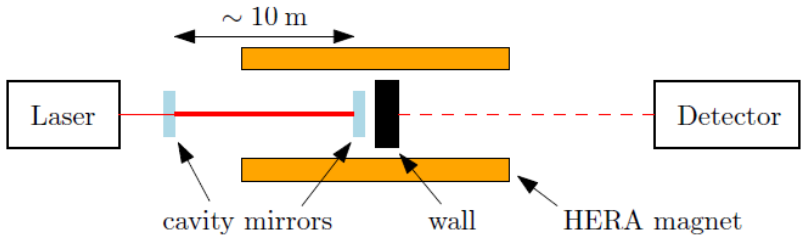
(c) ALPS-IIb



(d) ALPS-IIc

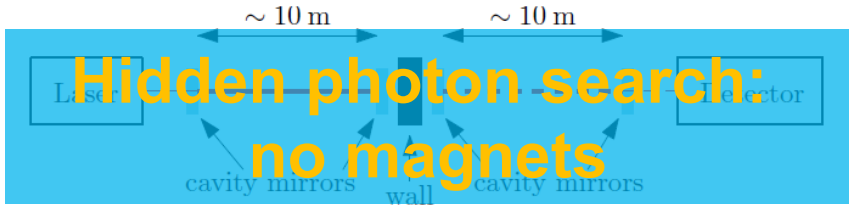
ALPS-II will be realized in stages

ALPS-I



(a) ALPS-I

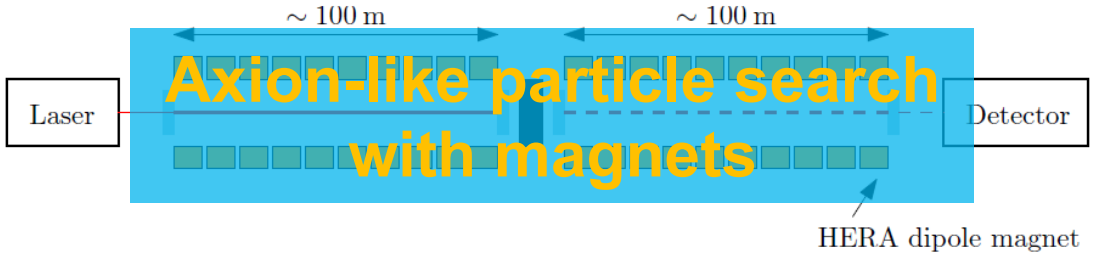
> ALPS-IIa



(b) ALPS-IIa

> ALPS-IIb

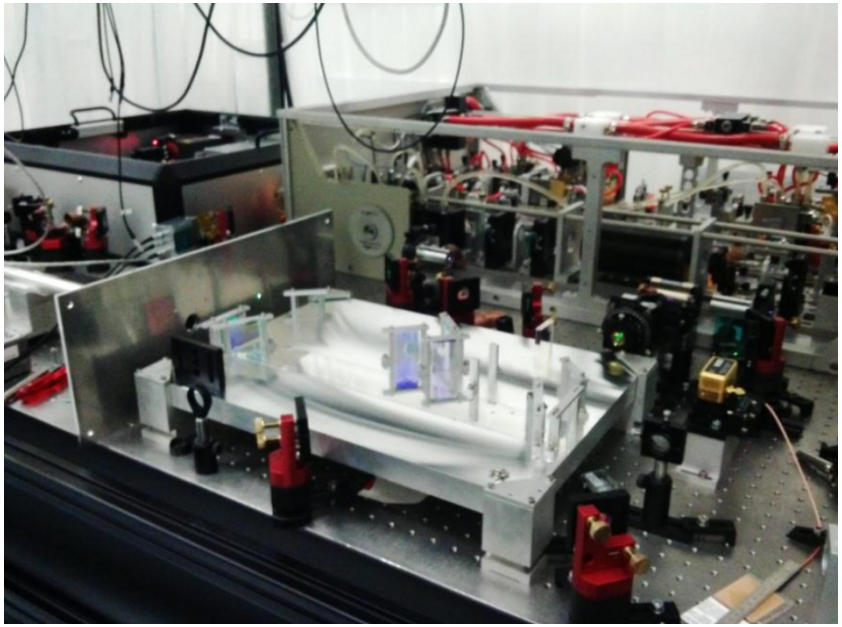
> ALPS-IIc



(d) ALPS-IIc

Optics

- The dichroic lock of the regeneration cavity (still without production cavity) has been demonstrated in a test setup at AEI in Hannover.
  This is an important proof-of-principle!



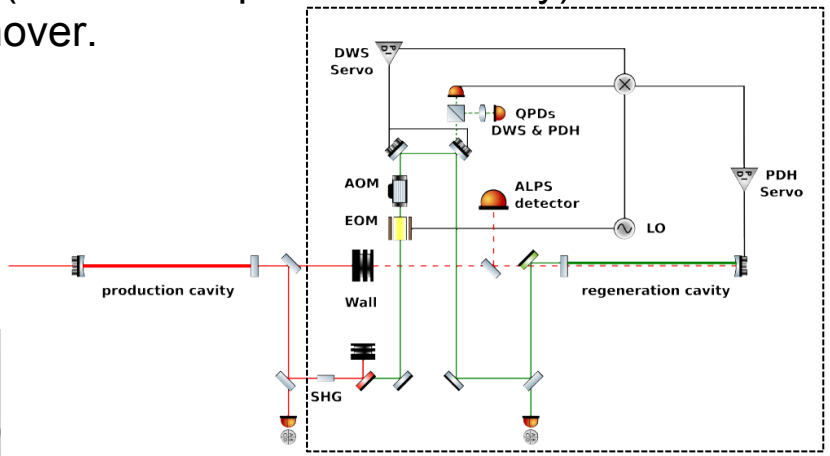
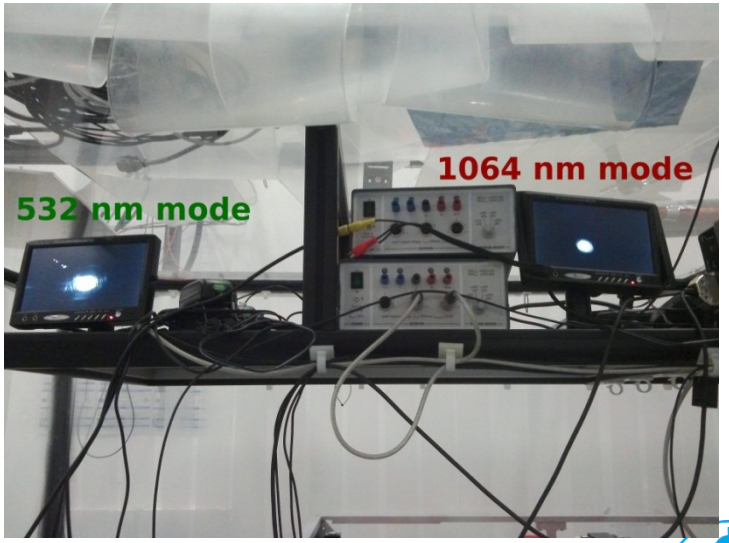


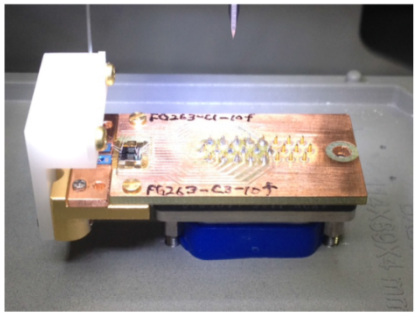
Figure 3.6: Schematic of the ALPS-II regeneration cavity including control loops.

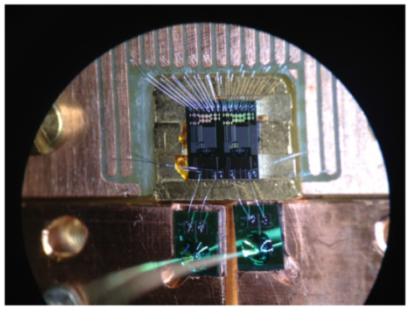


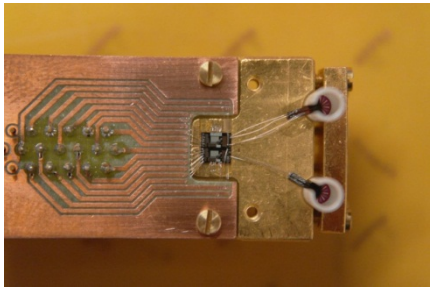
Detectors: TES

- The ADR was successful brought into operation at DESY meeting (nearly) all specifications.
  A first simple read-out system is operational allowing for the planned tests.

- Transition edge sensor modules from AIST and NIST arrived in PTB (Berlin) for first characterizations and will be shipped to DESY end of April.

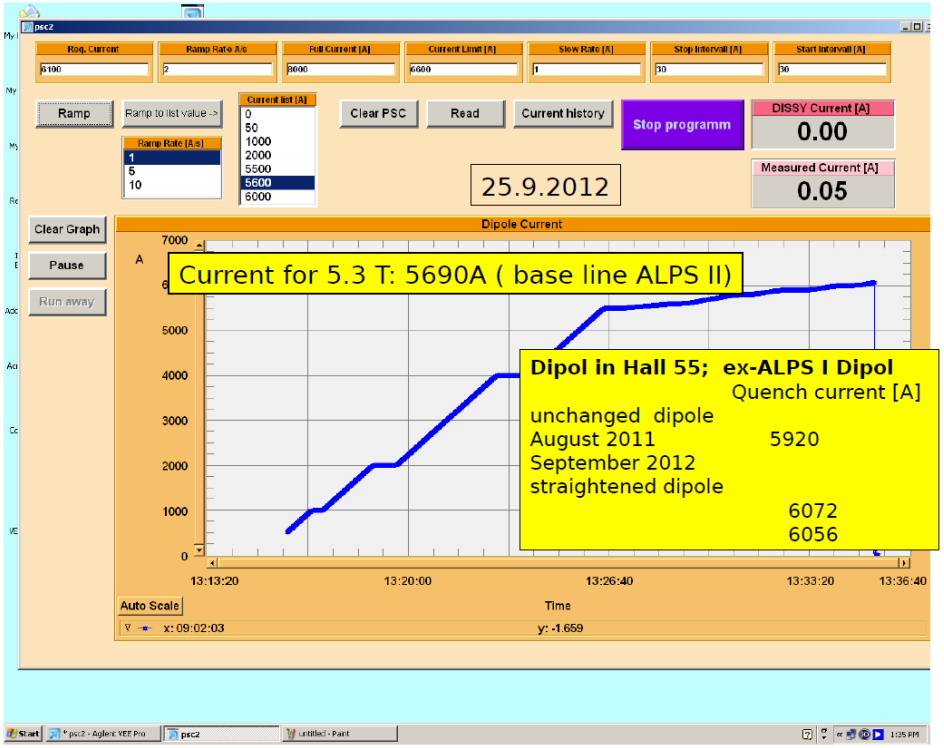






Magnets

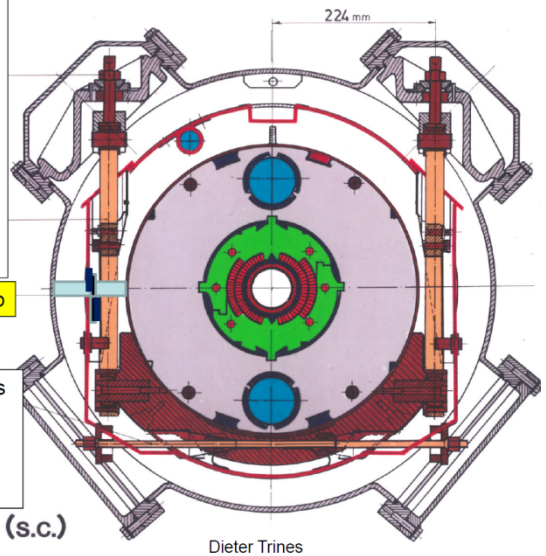
- Already the first test of the straightening procedure in September 2012 was very successful!



The deformation of the yoke is elastic. Therefore the force must be maintained also during cryogenic operation of the dipole.
So, the deformation tools are replaced by **pressure props with a sufficiently low heat flow to the 4K helium vessel**.

pressure prop

The outer pressure props have to follow the length change of the helium vessel during cool down and warm-up.

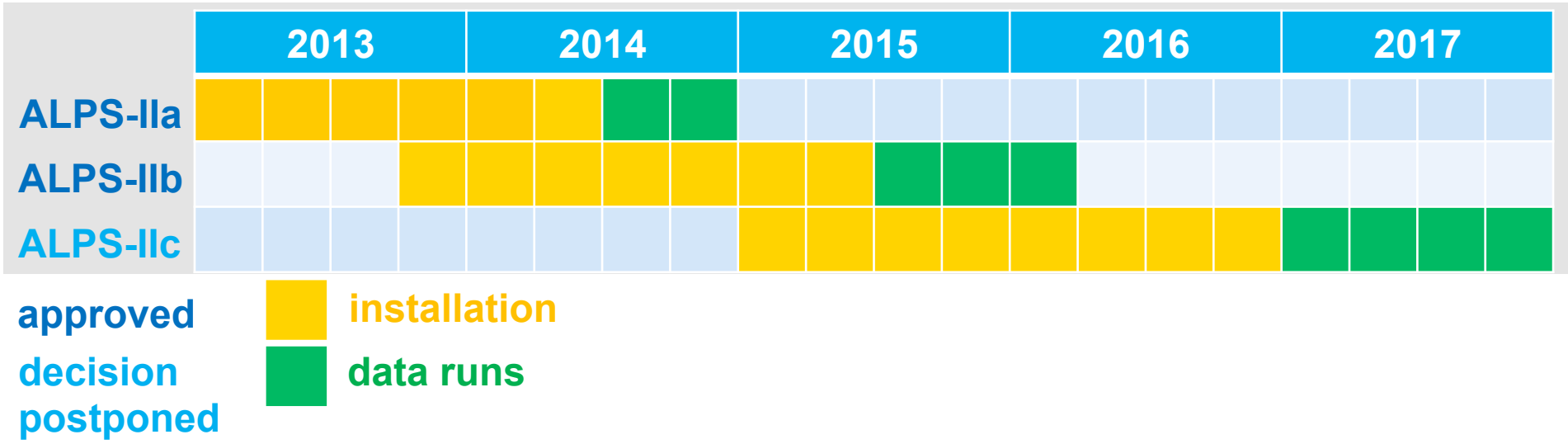


Dipole Magnet (s.c.)

Dieter Trines
PRC Review Nov 7th 2012

- The straightening procedure for the HERA dipoles has been revised. A simpler and more robust method will be tested soon.

Schedule



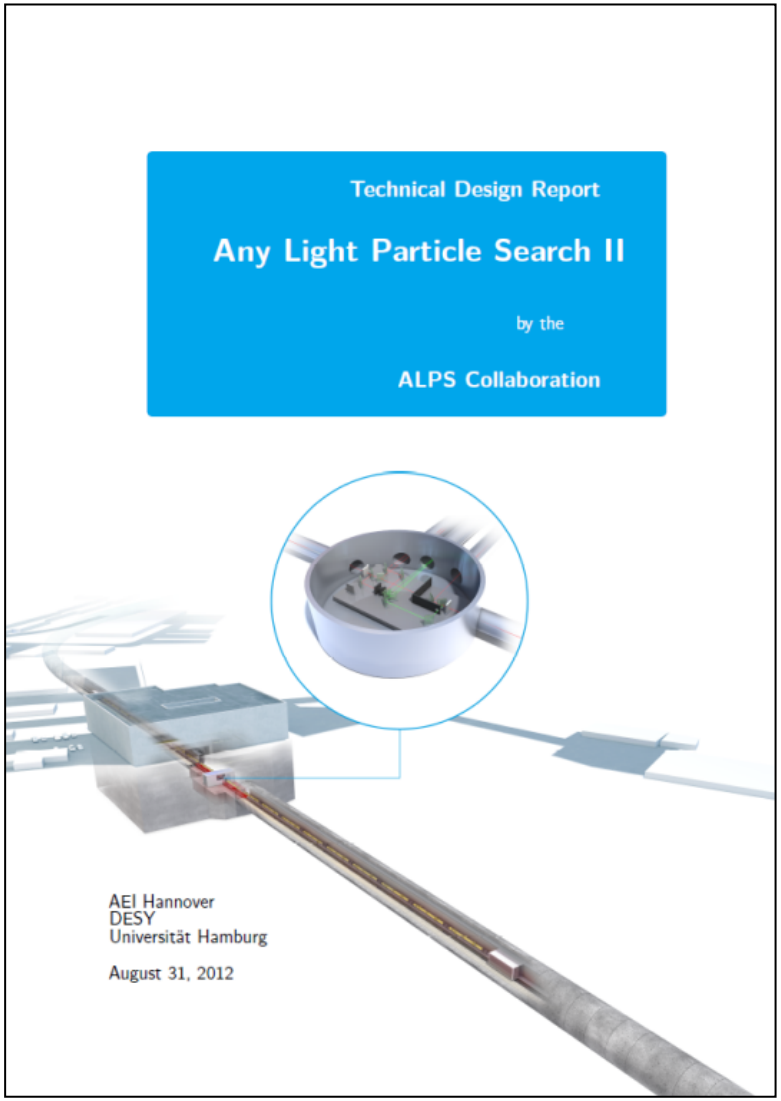
- A very quick (and fascinating) particle physics enterprise!

  We are open for collaborators!

More information on ALPS-II

Any Light Particle Search II – Technical Design Report
arXiv:1302.5647 [physics.ins-det], submitted to JINST

- **Albert Einstein Institute, Hannover**
  - **DESY in Hamburg**
  - **University of Hamburg**

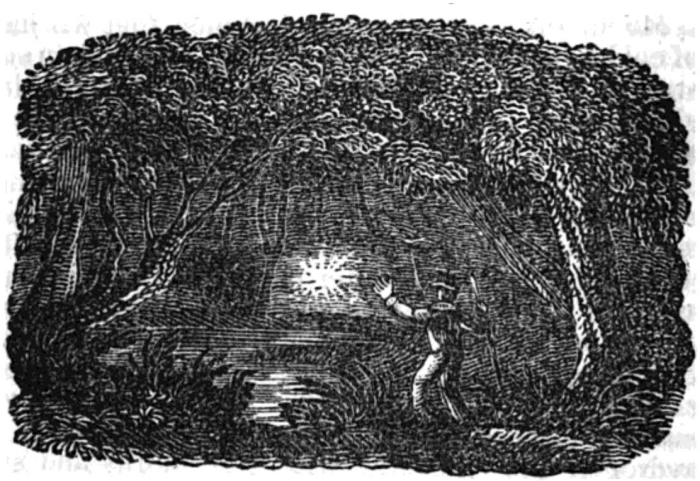


Beyond ALPS-II

- Rough estimation with some crucial parameters (omitting detector options):

Exp.	Photon flux (1/s)	Photon E (eV)	B (T)	L (m)	B·L (Tm)	PB reg.cav.	Sens. (rel.)	Mass reach (eV)
ALPS-I	$3.5 \cdot 10^{21}$	2.3	5.0	4.4	22	1	1	0.001
ALPS-II	$1 \cdot 10^{24}$	1.2	5.3	106	562	40,000	1,500	0.0002
“ALPS-III”	$3 \cdot 10^{25}$	1.2	13	400	5200	100,000	40,400	0.0001
European XFEL	$< 10^{18}$	$1 \cdot 10^{4}$	5.3	106	562	1	3	0.01
PW laser	10^{20} 1/pulse	2.3	10^{6}	10^{-5}	10	1	1	0.5

Directly looking for Weakly Interacting Slim Particles



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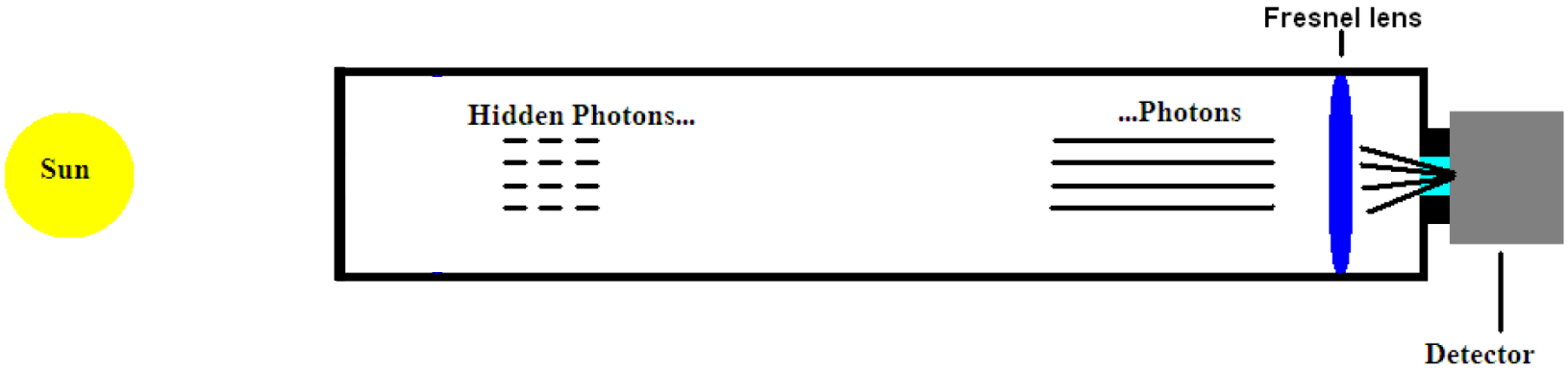
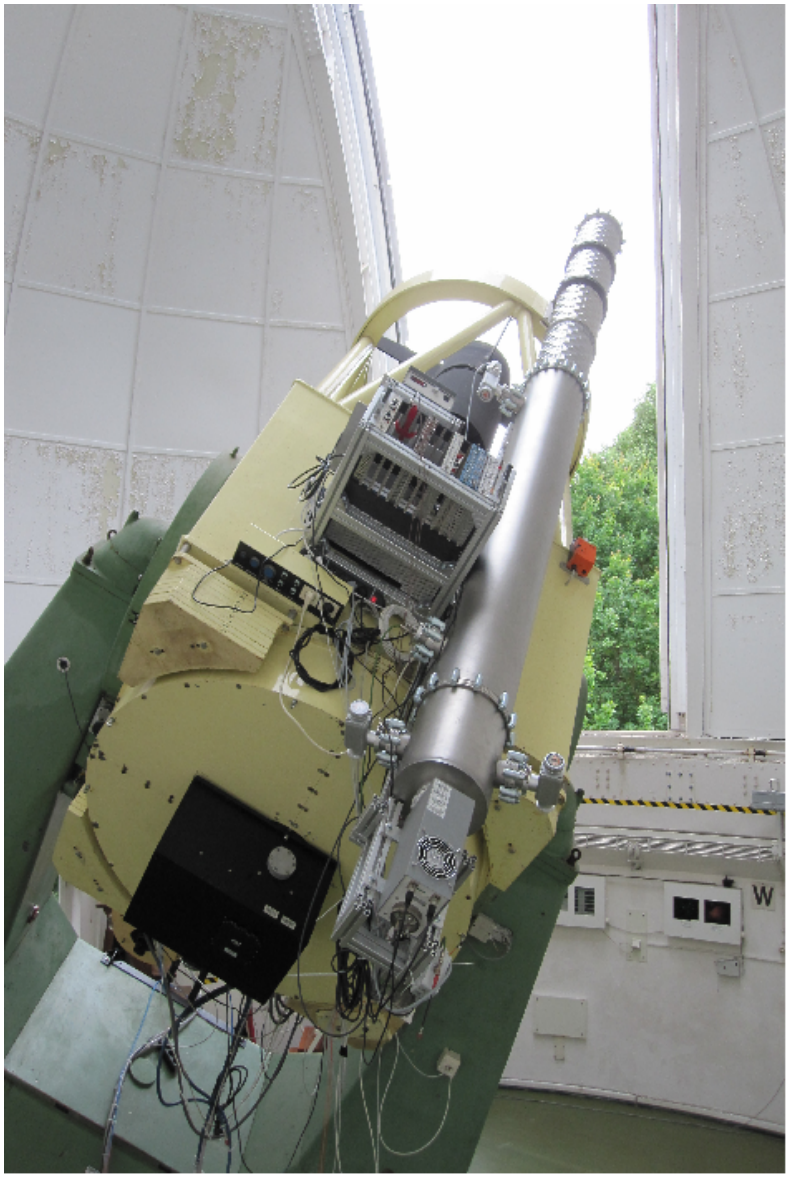
TSHIPS at the observatory Bergedorf

Telescope for Solar Hidden Photon Search

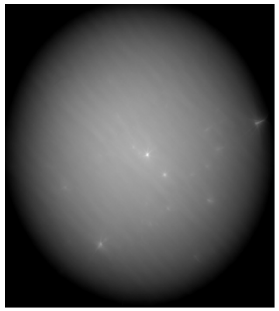


- DESY
- Hamburger University (observatory Bergedorf)

TSHIPS-I status

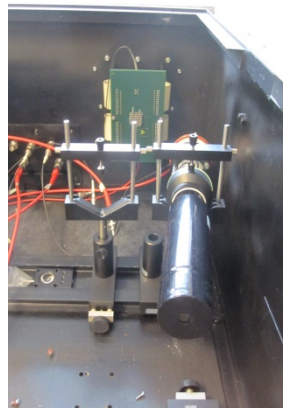


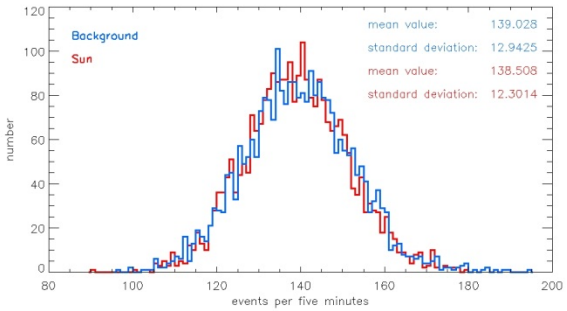
- Light collected via a 20 cm Fresnel lens:
- Low noise PM:
  (ET Enterprises 9893/350B)



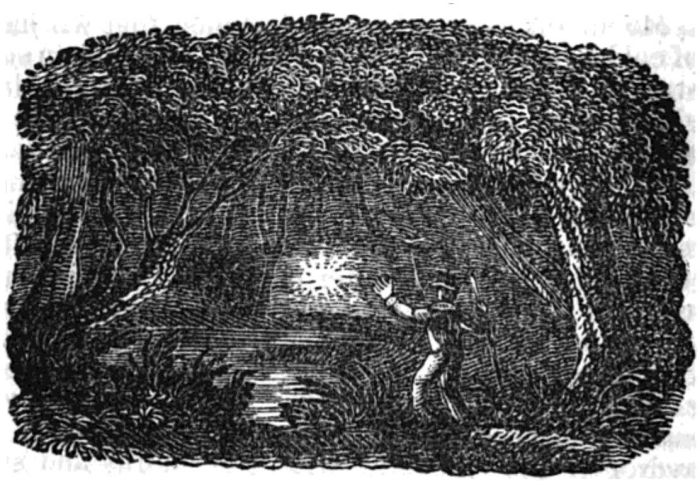
- Data taking since March 2013: 250 h of sun + background data each,

  but no hint for an excess (yet).





Directly looking for Weakly Interacting Slim Particles



Mudie, *A Popular Guide to the Observation of Nature* (1836, p.144).
http://books.google.de/books?id=kdknAAAAMAAJ&pg=PP1#v=onepage&q&f=false

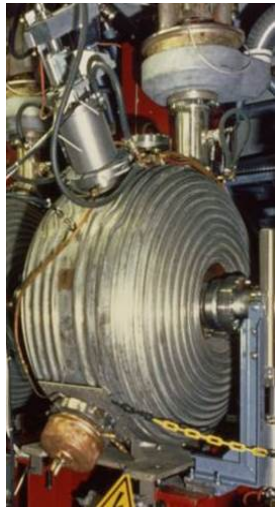
- Three kinds of WISP searches
- ALPS-II (purely laboratory search)
- TSHIPS (helioscope)
- WISPDMX and a “dish” vision (haloscopes)
- Summary

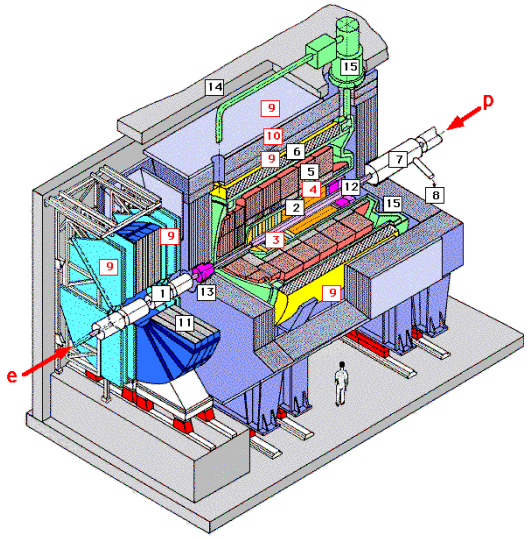
WISPDMX: WISP Dark Matter eXperiment

> DESY, Hamburg University, ITP Heidelberg , MPIfR, MPP Munich.
(PI Andrei Lobanov, MPIFR)

> Combine accelerator cavities, detector magnets, radio astronomy receivers.

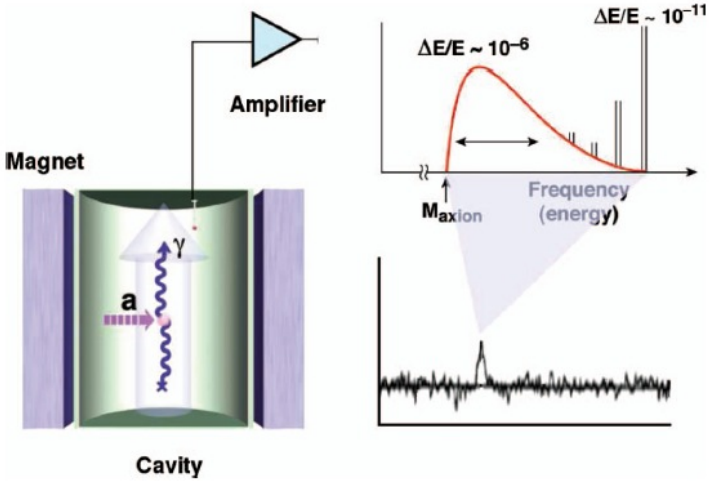
- WISPDMX utilizes a 208-MHz resonant cavity designed for the HERA accelerator at DESY and plans to make use of the H1 dipole magnet.
- The signal is amplified by a broadband 0.2-1.0 GHz amplifier from the MPIfR and analyzed using a commercial digitizer/spectrum analyzer.
- The hidden photon measurements will be made in the second half of 2013. Results of the study will be used for planning the ALP searches in the particle mass range below 2 meV.





Searches for WISPy cold dark matter

- Due to their low mass WISPy cold dark matter can not be detected by recoil techniques.
- WISPy dark matter particles have to convert into photons in a thoroughly shielded environment.
- The mass of the dark matter particle determines the energy to be detected. For axions it is in the microwave range.
- The resonance frequency of the cavity is to be tuned to the WISP mass to be probed.
  This is a time consuming process!



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

A new way of broadband DM seaches?

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

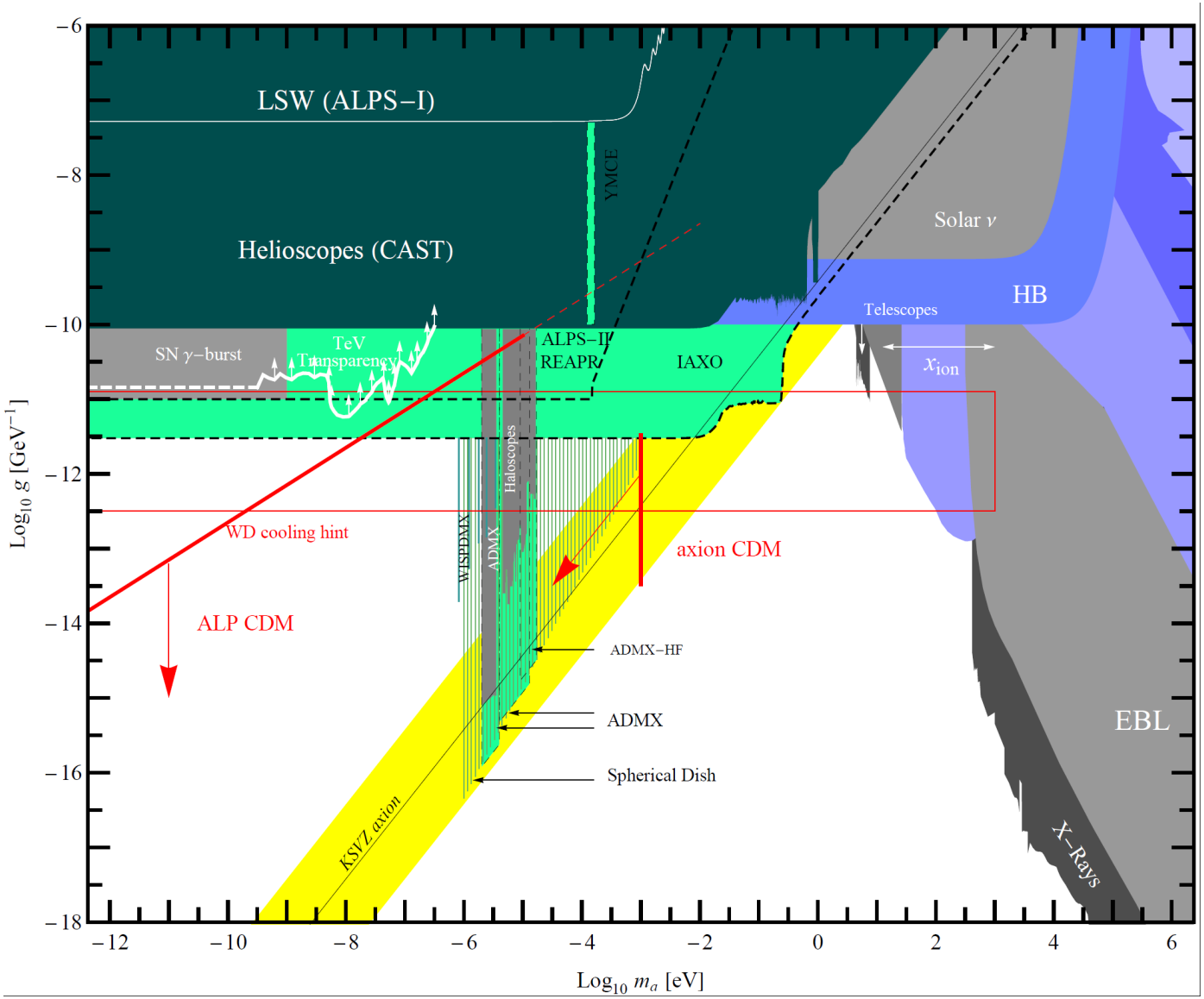
Searching for WISPy cold dark matter with a dish antenna

Dieter Horns,[a] Joerg Jaeckel,[b,c] Axel Lindner,[d] Andrei Lobanov,[e,1] Javier Redondo[f,g] and Andreas Ringwald[d]

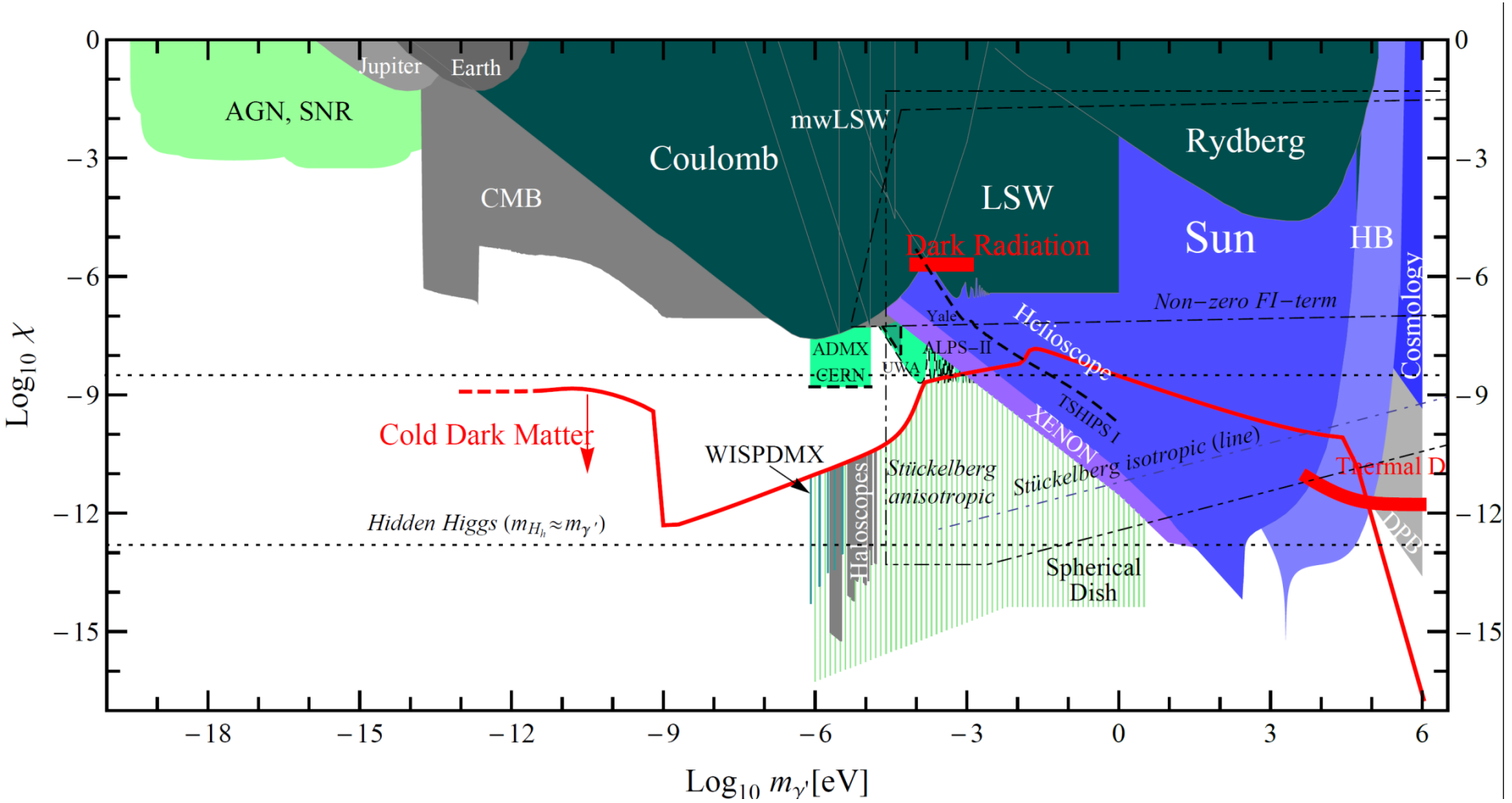
arXiv:1212.2970 [hep-ph]
JCAP04(2013)016
doi:10.1088/1475-7516/2013/04/016

- The photonic component of a WISP excites electromagnetic radiation emitted by a conducting surface.
- This radiation is emitted perpendicular to the surface and can be focused onto a detector.
- This works for a broad range of WISP masses, given by the mirror reflectivity.
- A lacking resonance enhancement (ADMX) can be compensated for by a large mirror surface.

Summary: ALPs and axions



Summary: hidden photons



Summary

- Weakly Interacting Slim Particles might explain puzzles from cosmology, astrophysics and particle physics.
  With the recent developments in theory and astrophysics phenomena we know where to go for axion-like particles and hidden photons.
- Next generation experiments are being constructed or prepared with sensitivities allowing to probe these predictions.
- DESY is participating in all three kinds if WISP searches:
  - ALPS-II (laboratory search, partly approved).
  - TSHIPS-I (helioscope for HP searches, taking data).
  - WISPDMX (haloscope, under development).
- One should exploit carefully new options provided by high power pulsed laser systems, large existing magnets or new approaches for dark matter searches for example.

Thanks to the workshop organizers!