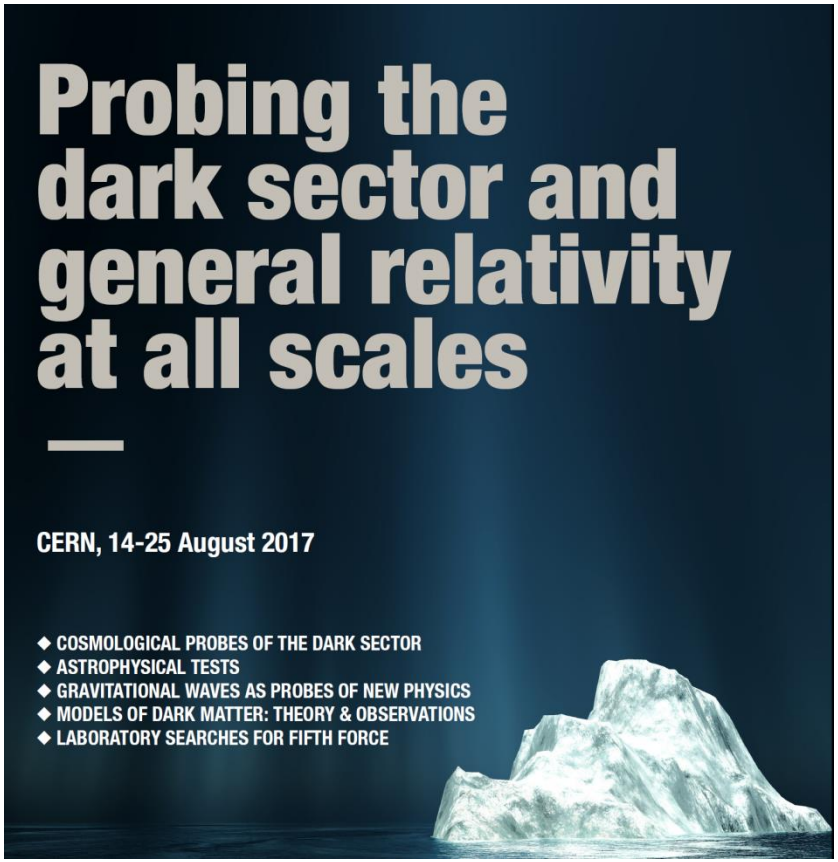
Laboratory-based experiments probing lightweights from a dark sector



CERN, 15 August 2017

Axel Lindner
DESY

HELMHOLTZ ASSOCIATION

DESY

Outline

- Motivation for purely laboratory based efforts to find Weakly Interacting Slim Particles
- ALP / axion searches via photon couplings
- Light-shining-through-a-wall: ALPS II and beyond
- 5th force searches
- Summary

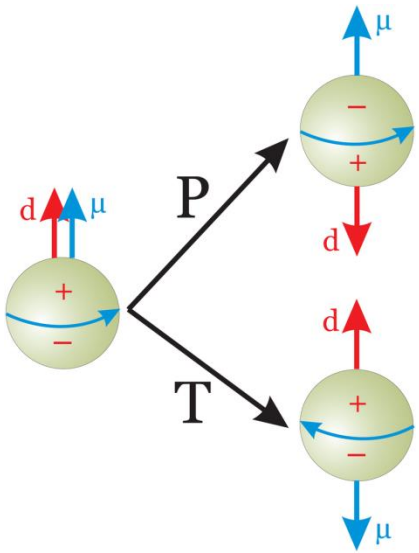
The dark sector

http://www.symmetrymagazine.org/sites/default/files/images/standard/Feature_DarkMatter3.jpg

- The dark sector could be complex with several constituents.
- Dark matter does not need to consist of only one particle species.
- To understand dark matter, any insight into the dark sector would be extremely helpful.
- Are there bright spots for dark sector searches?

An experimentalist‘s motivation for WISP searches (1)

> **W**eakly **I**nteracting **S**lim **P**articles (WISPs) could explain the CP conservation of QCD and the vanishing EDM of the neutron:



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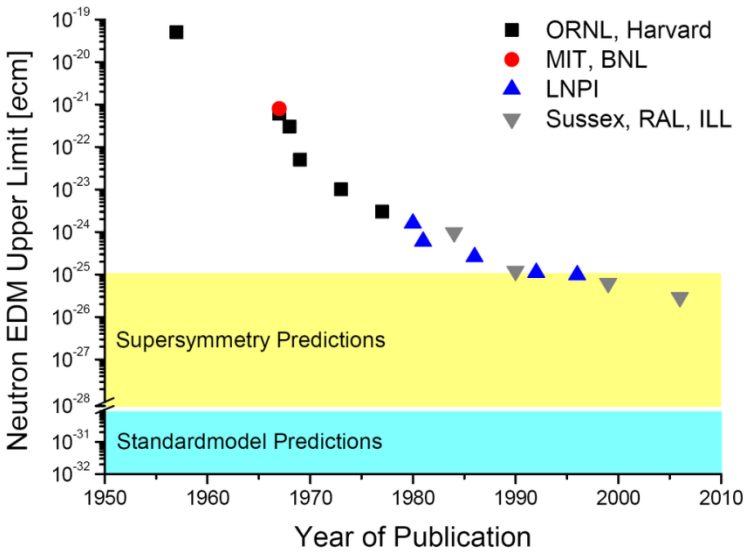
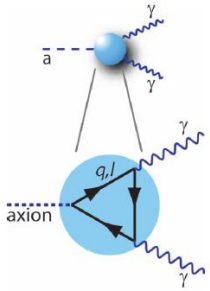


Wikipedia

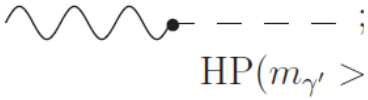
- WISPs may explain dark matter:
  - Axion
  - Axion-like particles
  - Hidden photons
  - …

Introduction to WeaklyInteractingSlimParticles

- WISPs are hypothetical bosons with masses below 1eV (< 0,000002 m_e).
- Axion: a neutral pseudoscalar predicted to explain the CP conservation in QCD. Its physics is determined by a symmetry breaking scale f_a:
  - Mass: $m_a = 0.6\text{eV} \cdot (10^7\text{GeV} / f_a)$
  - Coupling to two photons: $g_{a\gamma\gamma} = \alpha \cdot g_\gamma / (2\pi \cdot f_a)$
  - Abundancy in the universe: $\Omega_a / \Omega_c \sim (f_a / 10^{12}\text{GeV})^{7/6}$



- Axion-like particles (ALPs):
  Coupling strength and mass are not related by one f_a.
- Hidden photons: neutral vector bosons.

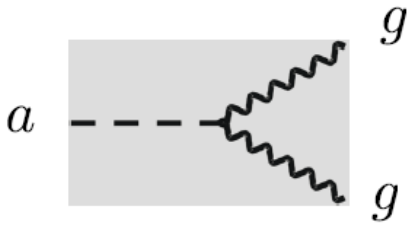


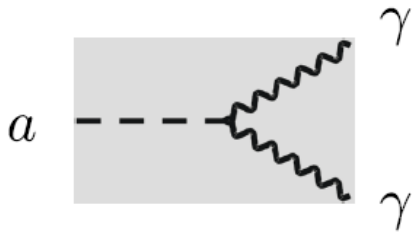
- Mini-charged particles, Chameleons, massive gravity scalars, …
  (some of these might be related to dark energy).

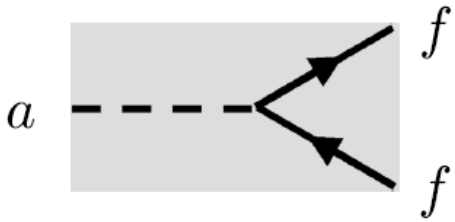
A word on axions and axion-like-particles (ALPs)

- Axion and other Nambu-Goldstone bosons arising from spontaneous breakdown of global symmetries are theoretically well-motivated very weakly interacting slim (ultra-light) particles.
  The coefficients are determined by specific ultraviolet extension of SM.

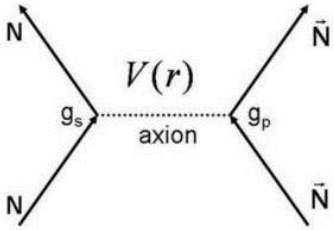
$$\mathcal{L} \supset -\frac{\alpha_s}{8\pi}\frac{C_{ag}}{f_a}\, a\, G^b_{\mu\nu}\tilde{G}^{b,\mu\nu} - \frac{\alpha}{8\pi}\frac{C_{a\gamma}}{f_a}\, a\, F_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{1}{2}\frac{C_{af}}{f_a}\partial_\mu a\, \overline{\psi}_f \gamma^\mu \gamma_5 \psi_f$$

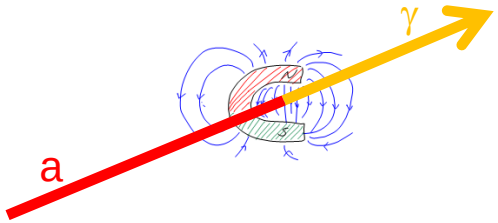


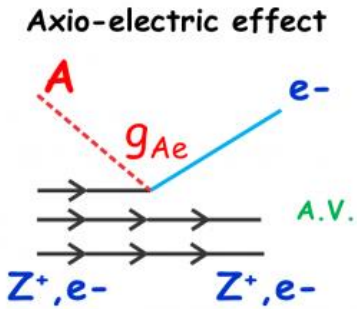




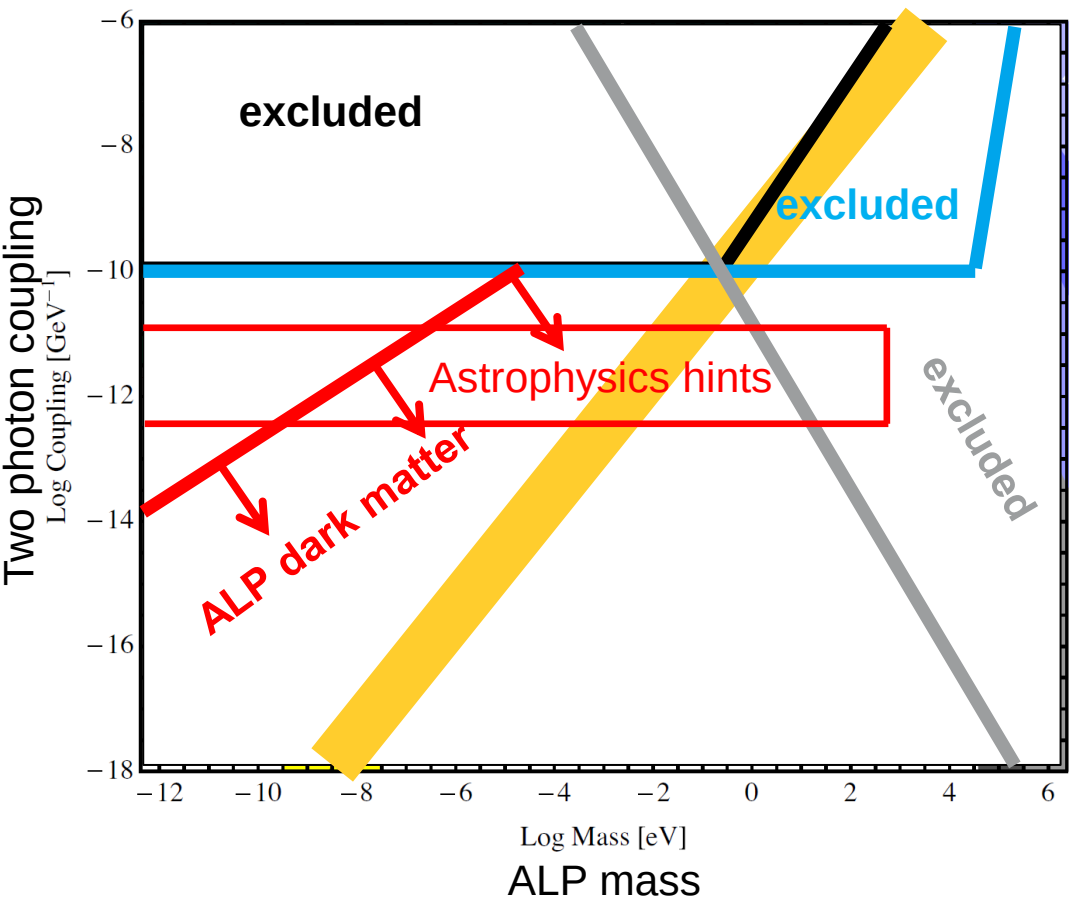
Courtesy A. Ringwald





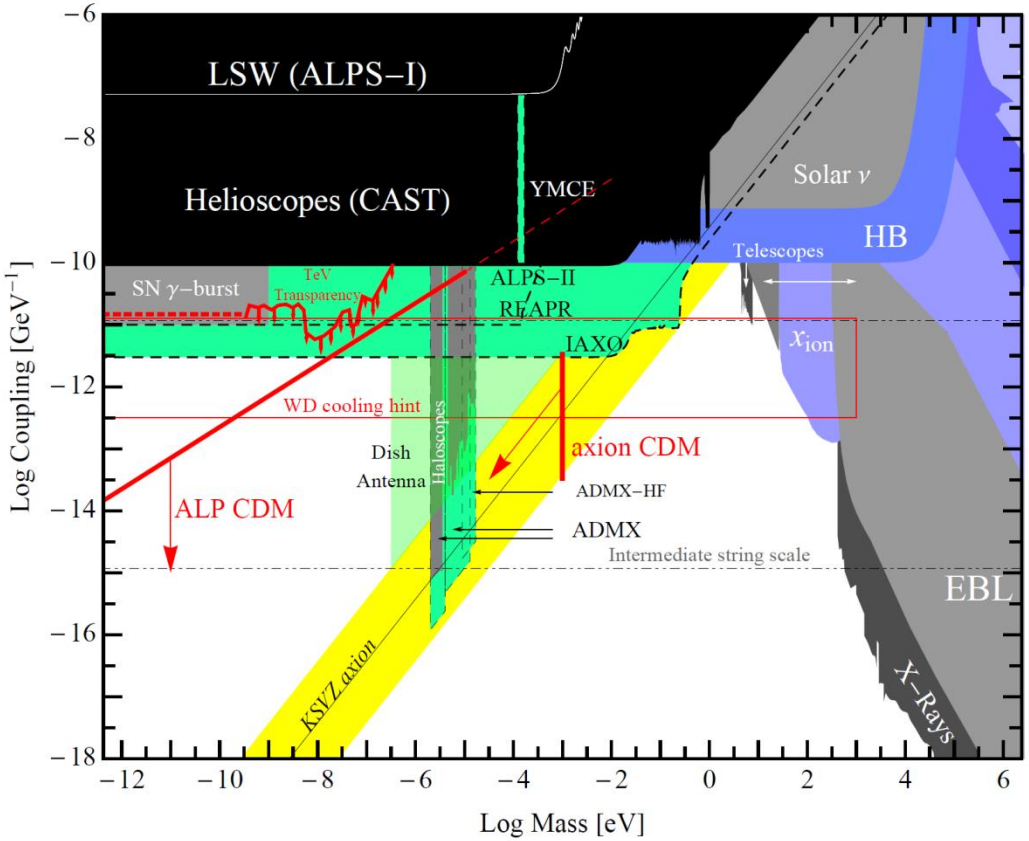


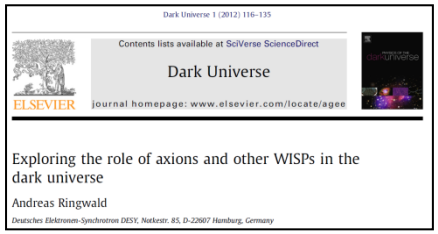
ALPs (axion & axion-like): what do we know?



QCD axion range
Excluded by WISP experiments
Excluded by astronomy (ass. ALP DM)
Excluded by astrophysics / cosmology
Axions or ALPs being cold dark matter
WISP hints from astrophysics

ALPs (axion & axion-like): what do we know?





DOI: 10.1016/j.dark.2012.10.008
e-Print: **arXiv:1210.5081 [hep-ph]**

QCD axion range
Excluded by WISP experiments
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Excluded by astrophysics / cosmology
Axions or ALPs being cold dark matter
WISP hints from astrophysics

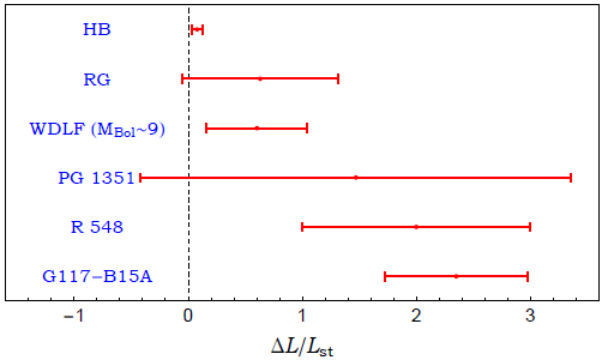
Sensitivity of next generation WISP exp.

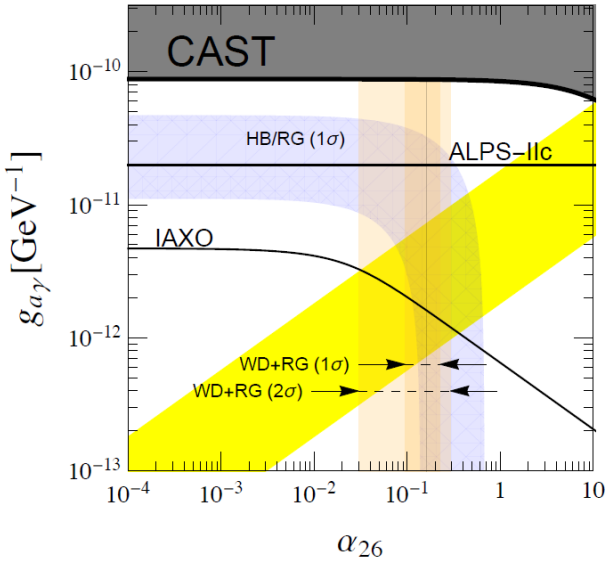
An experimentalist's motivation for WISP searches (2)

Stellar developments:

- Extra energy loss beyond SM expectations is indicated by stellar developments.

- Such losses can be explained consistently by the emission of axions coupling to photons and electrons.





M. Giannotti, I. Irastorza,
J. Redondo, A. Ringwald,
http://arxiv.org/abs/1512.08108

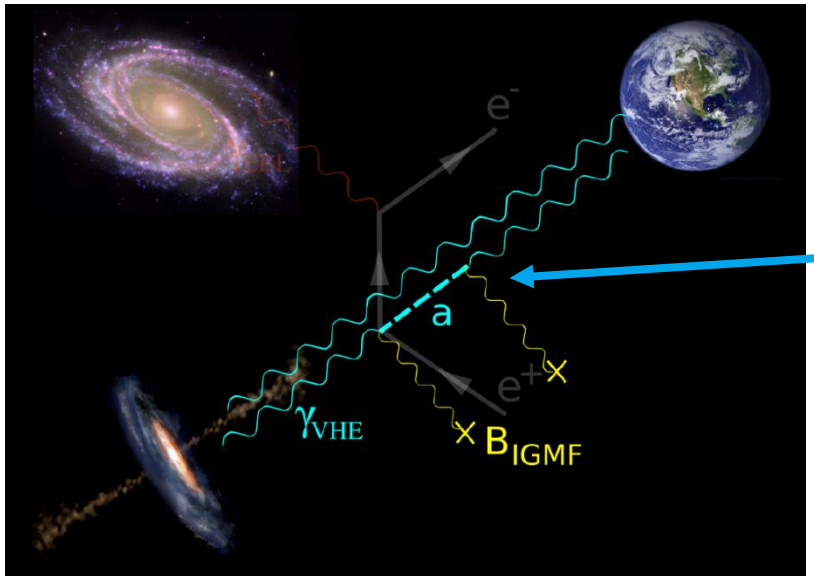
M. Giannotti, I. Irastorza,
J. Redondo, A. Ringwald, K. Saikawa
https://arxiv.org/abs/1708.02111

An experimentalist‘s motivation for WISP searches (3)

Anomalous transparency of the universe to TeV photons:

- TeV photons might not be absorbed in the intergalactic space due to $\gamma+\gamma \rightarrow e^+e^-$ scattering as predicted by QED.

- This could be explained by axion-like particles.



TeV photons in the universe

might convert in magnetic fields to ALPs via their two-photon coupling.

Such ALPs might convert back to photons in the vicinity of earth.

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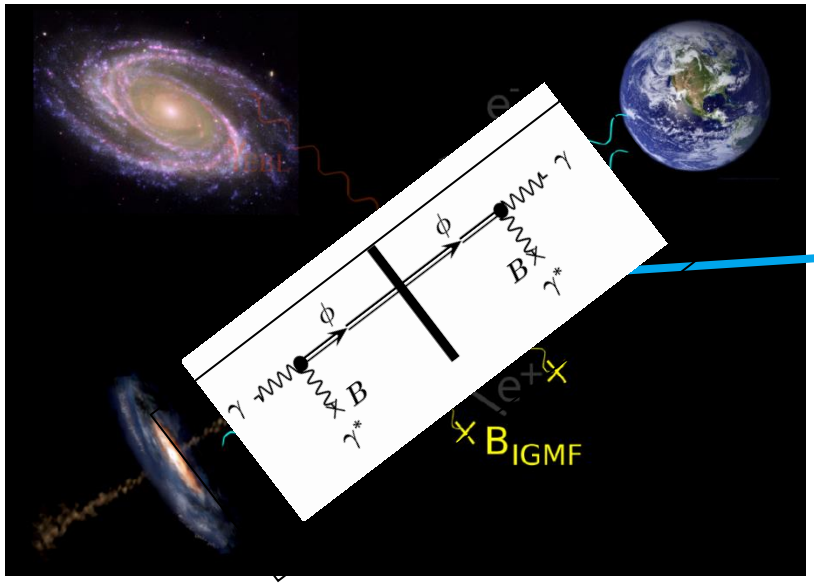

TeV photons in the universe

“light-shining-through-the-wall” of extragalactic background light?

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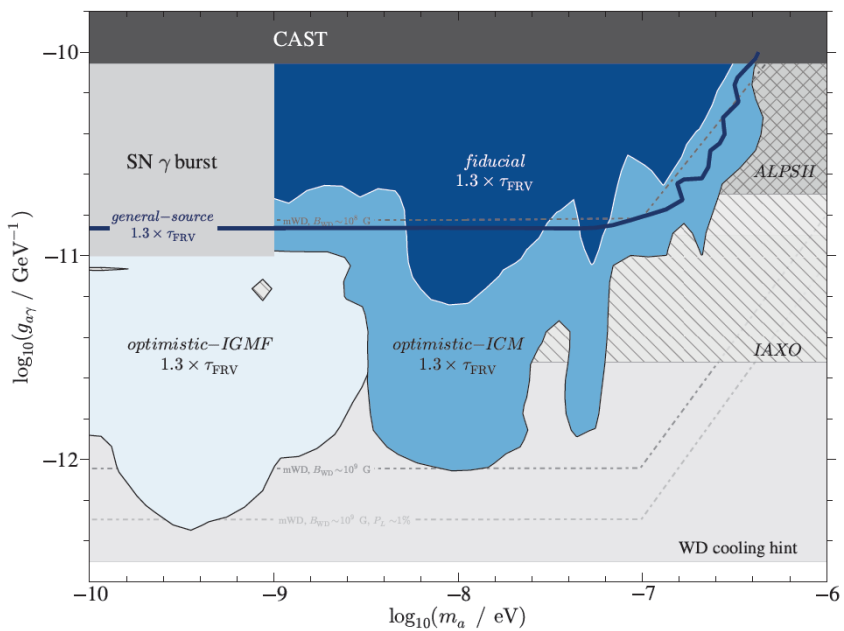
Two photon coupling



ALP mass

A very similar axion-photon coupling as derived from stellar developments is required!

M. Meyer, D. Horns, M. Raue, arXiv:1302.1208 [astro-ph.HE], Phys. Rev. D 87, 035027 (2013)

S. V. Troitsky, arXiv:1612.01864 [astro-ph.HE], JETP Lett. 105 (2017) no.1, 55

Axion / ALPs and the TeV photon transparency

- ALP couplings to explain an unexpected high transparency of the universe for TeV photons:

PROCEEDINGS OF SCIENCE

Hints for an axion-like particle from PKS 1222+216?

https://arxiv.org/abs/1409.4401

Advantages of axion-like particles for the description of very-high-energy blazar spectra

https://arxiv.org/abs/1503.04436

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Sensitivity of the Cherenkov Telescope Array to the detection of axion-like particles at high gamma-ray opacities

https://arxiv.org/abs/1410.1556

PHYSICAL REVIEW D **86,** 075024 (2012)

Hardening of TeV gamma spectrum of active galactic nuclei in galaxy clusters by conversions of photons into axionlike particles

https://arxiv.org/abs/1207.0776

PHYSICAL REVIEW D **93,** 045014 (2016)

Towards discrimination between galactic and intergalactic axion-photon mixing

https://arxiv.org/abs/1507.08640

Axion-like particles and the propagation of gamma rays over astronomical distances

https://arxiv.org/abs/1612.01864

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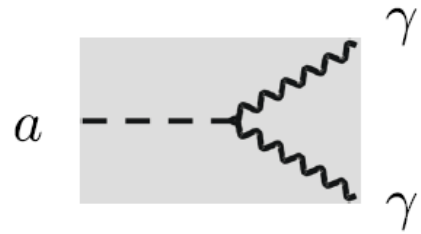
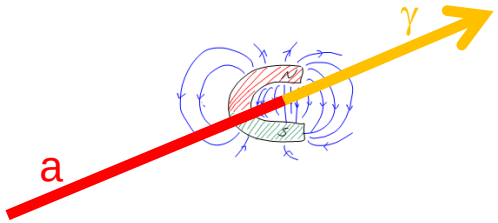
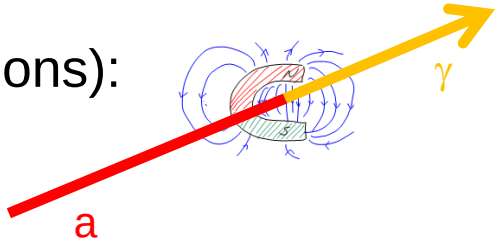




Courtesy A. Ringwald

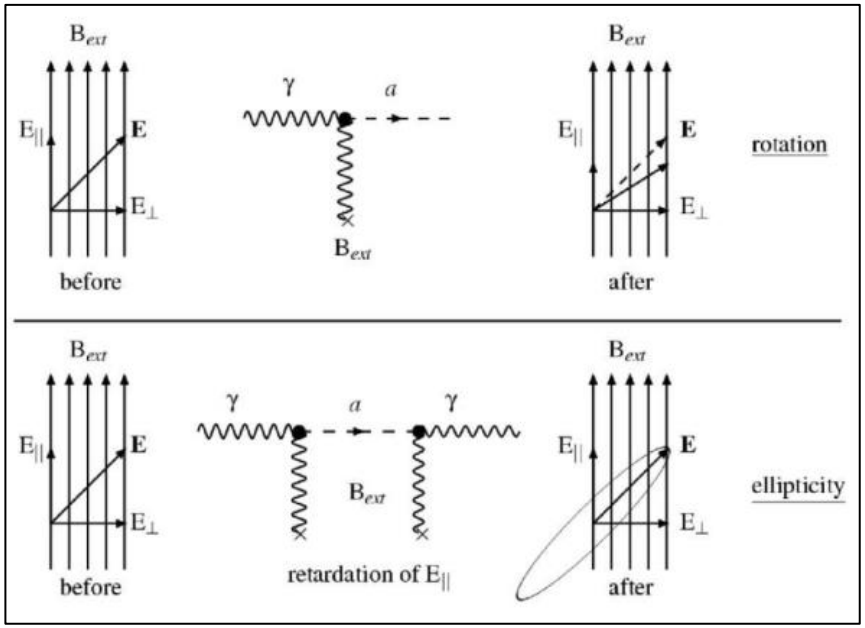
Observable effects from ALP-photon coupling (1)

Basis for experiments (works in both directions):



> The polarization of light traversing a magnetic field is changed:

J. E. Kim et al. Rev.Mod.Phys
. 82 (2010) 557-602



Only light polarized parallel (perpendicular) to the magnetic field couples to pseudoscalar (scalar) ALPs.

ALP seaches via polarization effects

The PVLAS experiment: measuring vacuum magnetic birefringence and dichroism with a birefringent Fabry-Perot cavity

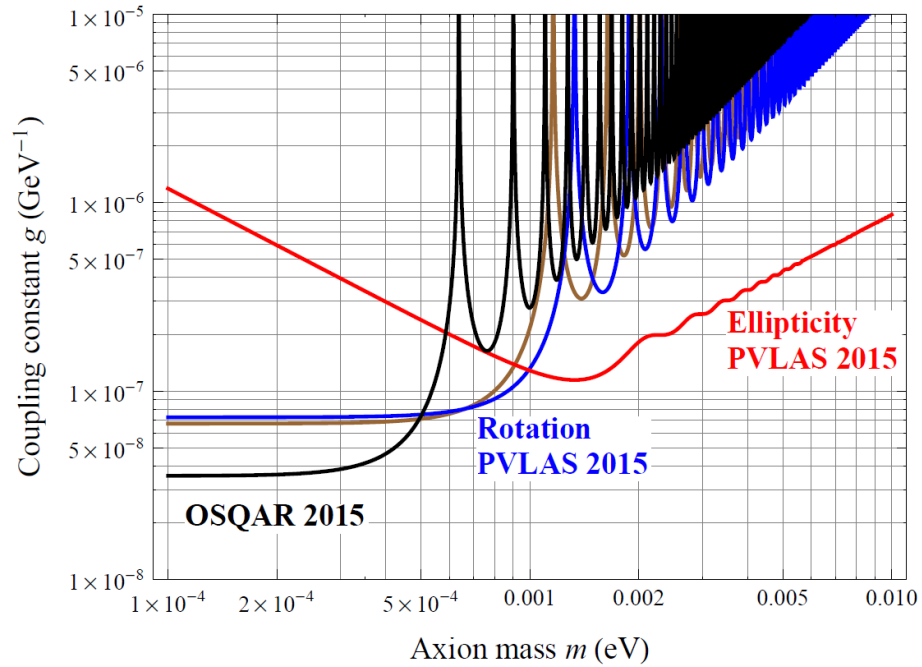
F. Della Valle, E. Milotti
INFN, Sez. di Trieste and Dip. di Fisica, Università di Trieste, via A. Valerio 2, I-34127 Trieste, Italy

A. Ejlli, U. Gastaldi, G. Messineo, G. Zavattini
INFN, Sez. di Ferrara and Dip. di Fisica e Scienze della Terra, Università di Ferrara, via Saragat 1, Edificio C, I-44122 Ferrara, Italy

R. Pengo, G. Ruoso
INFN, Lab. Naz. di Legnaro, viale dell'Università 2, I-35020 Legnaro, Italy

(Dated: Received: date / Accepted: date)

https://arxiv.org/abs/1510.08052



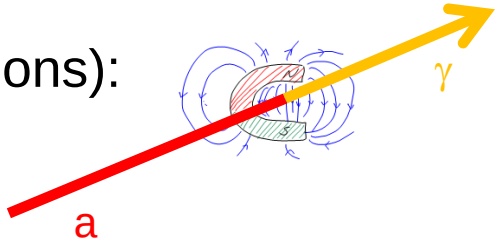
Very sensitive and model independent results, but

- going beyond CAST requires an increase in sensitivity by six orders of magnitude.
- This is hard to imagine and QED strikes back!

CAST barrier

Observable effects from ALP-photon coupling (1)

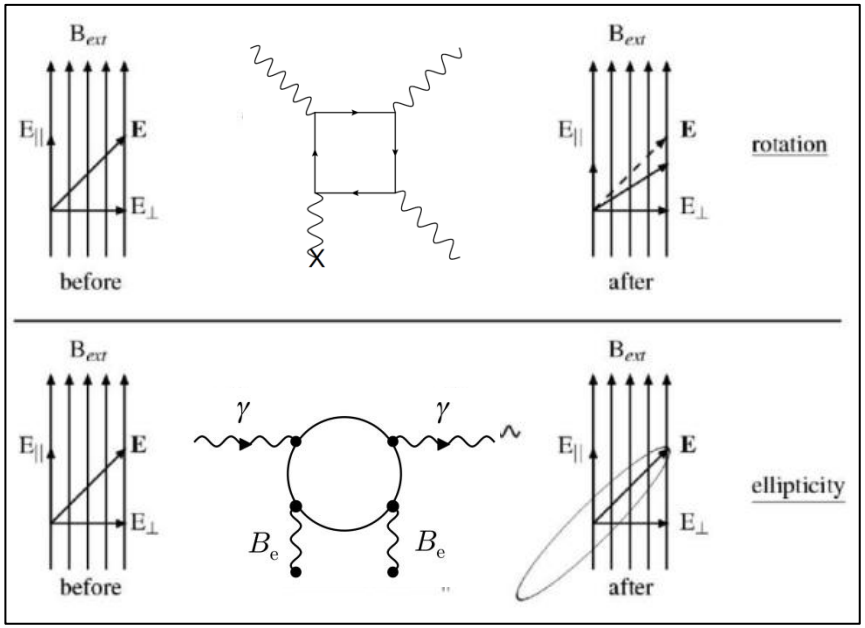
Basis for experiments (works in both directions):



- Polarization in a magnetic field: QED background!

Photon splitting Negligible, but hard to improve present experiments

Vacuum magnetic birefringence Serious



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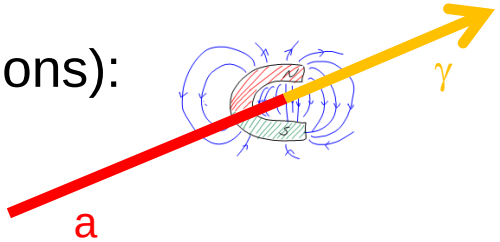
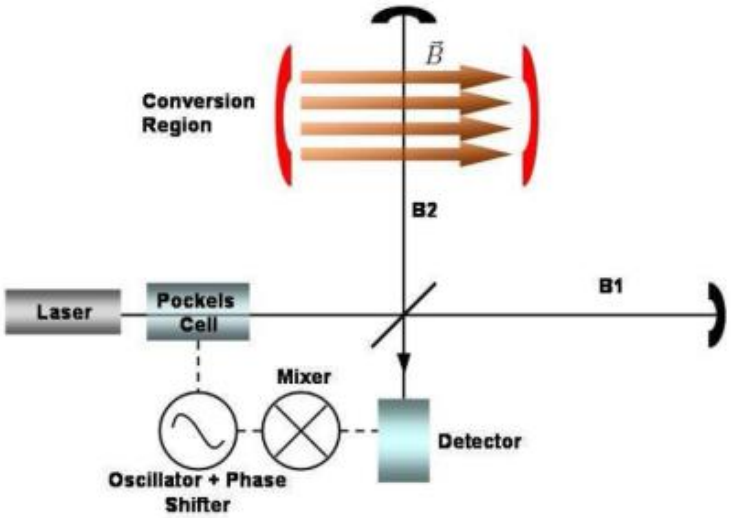
Observable effects from ALP-photon coupling (2)

Basis for experiments (works in both directions):



- ALP-photon mixing in a magnetic field changes the refraction index …

H. Tam, Q. Yang
Physics Letters B 716
(2012), pp. 435-440



… and causes a phase shift relative to a magnetic field free region.

With aLIGO sensitivities and long magnet strings QCD-axions are in reach, but …

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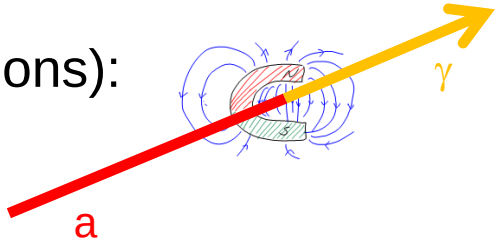

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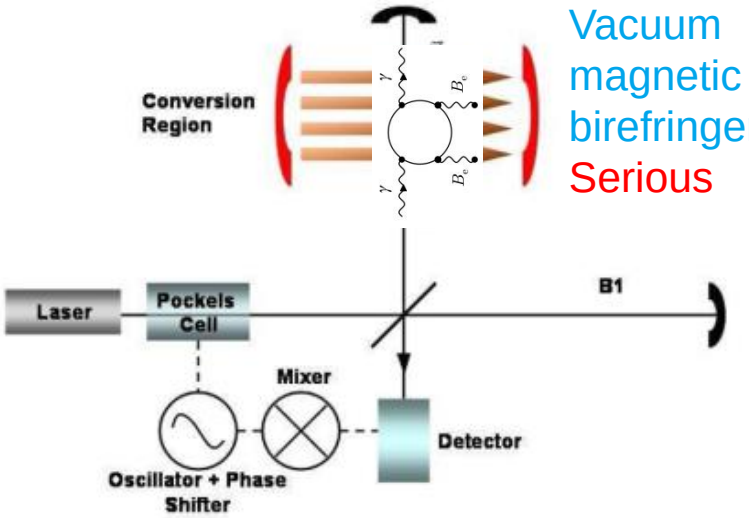

Vacuum magnetic birefringence Serious

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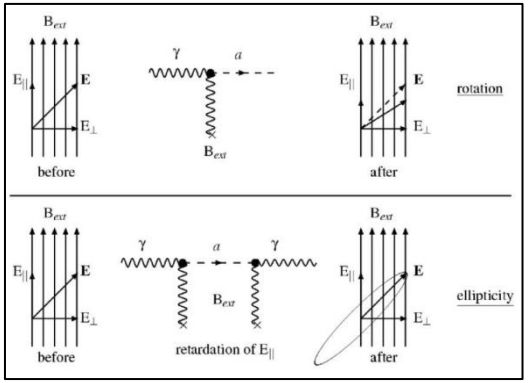
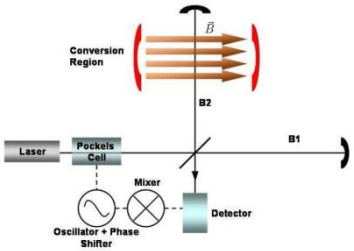
Observable effects from ALP-photon coupling (3)

- Polarization



J. E. Kim et al. Rev.Mod.Phys . 82 (2010) 557-602

- Interferometry



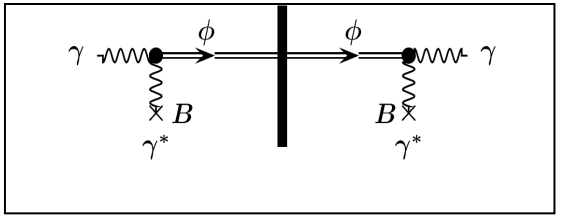
H. Tam, Q. Yang Physics Letters B 716 (2012), pp. 435-440

Finding ALPs in the lab: photon coupling options

- Polarization

- Interferometry

- Light-shining-through-a-wall



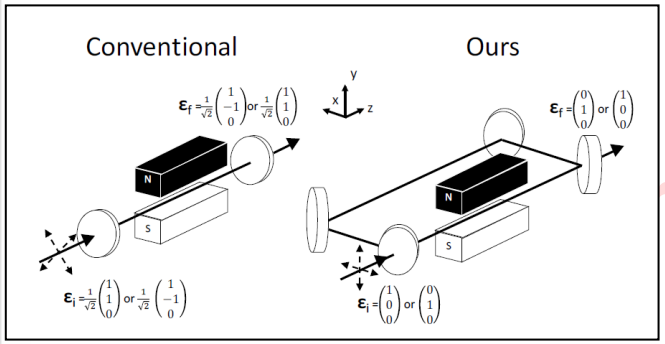
Finding ALPs in the lab: photon coupling options

- Polarization

There are notable exceptions:
searching for parity violating dark sector effects.

Vacuum Magnetic Birefringence Experiment as a probe of Dark Sector

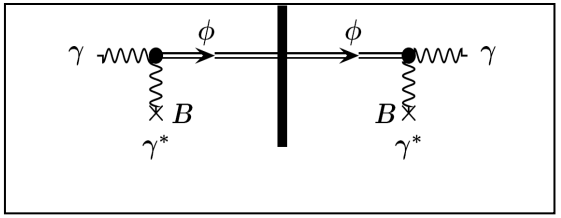
Xing Fan[1,2], Shusei Kamioka[1], Kimiko Yamashita[3], Shoji Asai[1], and Akio Sugamoto[3,4]



https://arxiv.org/abs/1707.03609

- Interferometry

- Light-shining-through-a-wall

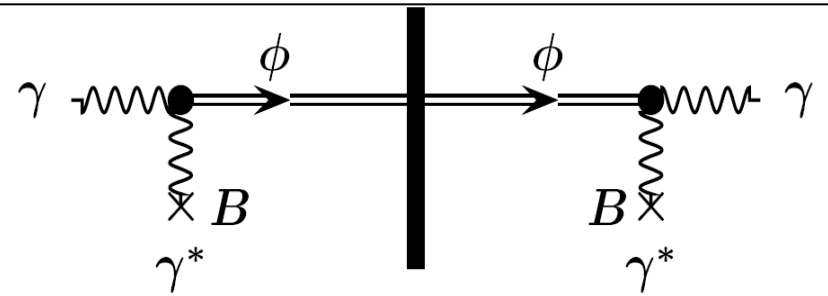


How to look for ALPs …

… by exploiting their coupling to photons:

> ALPs pass any barrier and could make

light-shining-through-a-wall.



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

Axions, axion-like particles

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

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

How to look for ALPs …

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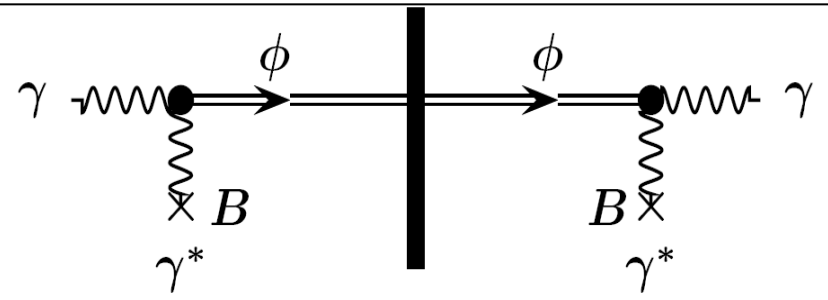


Okun 1982, Skivie 1983, Ansel'm 1985, Van Bibber et al. 1987

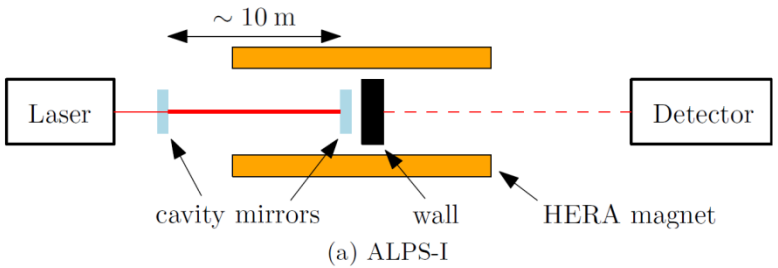
Axions, axion-like particles

ql << 1; conversion and re-conversion:

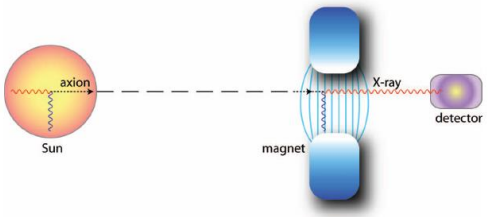
$$P_{\gamma\to\phi\to\gamma} = \frac{1}{16}\cdot(g_{a\gamma}Bl)^4 = 6\cdot 10^{-38}\cdot\left(\frac{g_{a\gamma}}{10^{-10}GeV^{-1}}\frac{B}{1\,T}\frac{l}{10m}\right)^4$$

Three kinds of searches

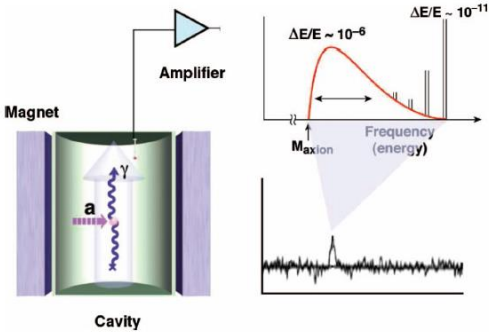
- Purely laboratory experiments (“light-shining-through-walls”) optical photons,



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



- Haloscopes (looking for dark matter constituents), microwaves.



Three kinds of searches

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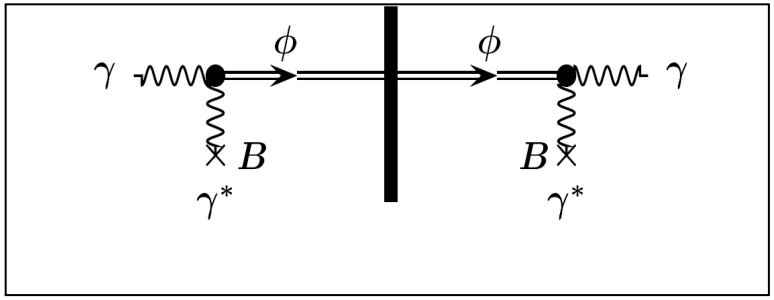

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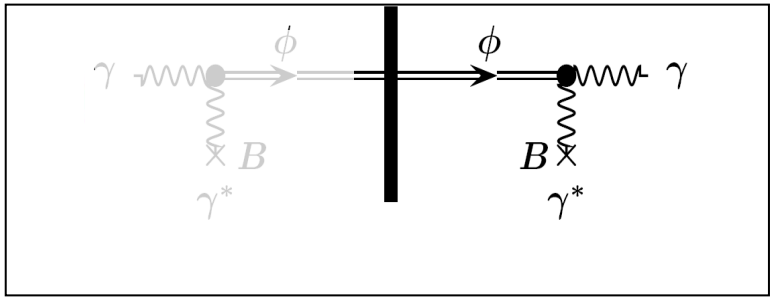

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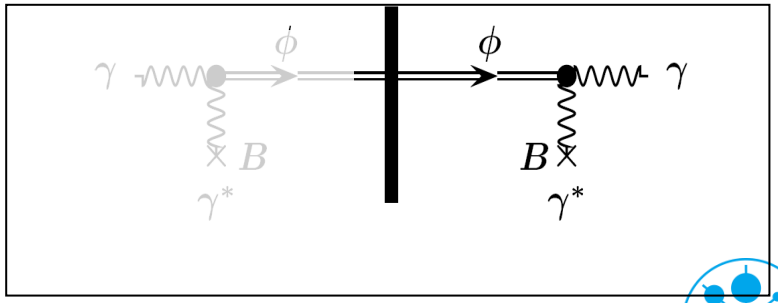


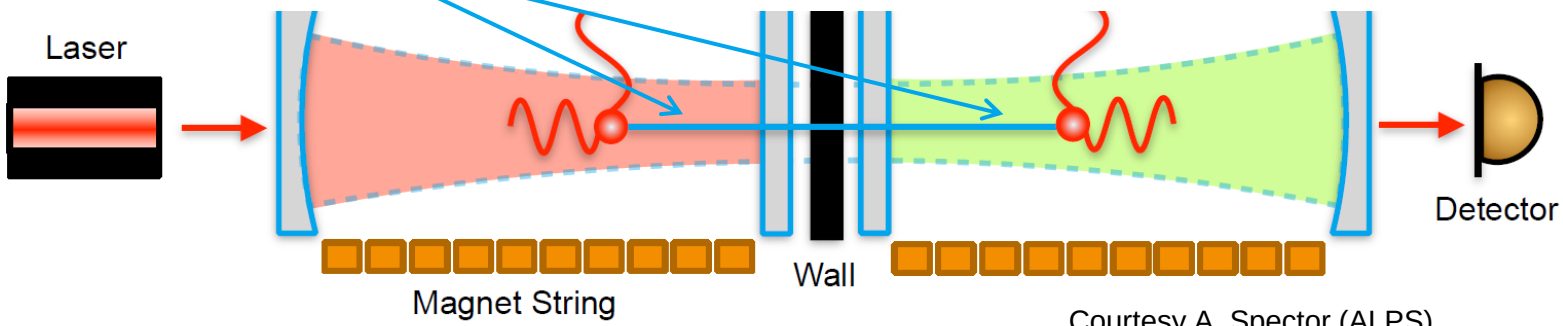
Pros and cons for LSW in the laboratory

ALP parameter	LSW (laboratory)	Helioscopes	Dark matter searches
Parity and spin	yes	perhaps	yes
Coupling $g_{a\gamma}$	yes	no	no
Coupling · flux	(does not apply)	yes	yes
Mass	perhaps	perhaps	yes
Rely on astrophysical assumptions	no	yes	yes
QCD axion	no	yes	yes

LSW in the laboratory is very well suited to look for axion-like particles to open up the window to the hidden sector.

Design criteria for LSW experiments with optical resonators

$$P_{\gamma\to\phi\to\gamma} = \frac{1}{16}\cdot\boxed{\mathcal{F}_{PC}\mathcal{F}_{RC}}\cdot(g_{a\gamma\gamma}\boxed{Bl})^4 = 6\cdot 10^{-38}\cdot\mathcal{F}_{PC}\mathcal{F}_{RC}\cdot\left(\frac{g_{a\gamma\gamma}}{10^{-10}GeV^{-1}}\frac{B}{1\,T}\frac{l}{10m}\right)^4$$



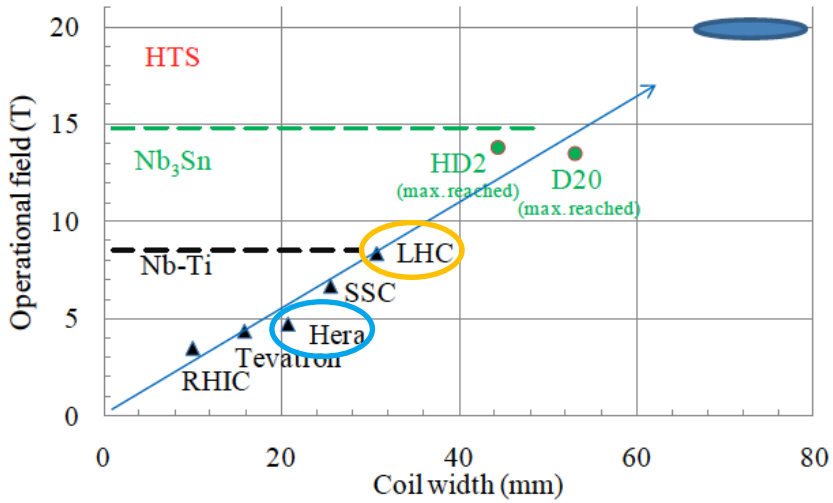
Courtesy A. Spector (ALPS)

- Use long strings of strong dipole magnets.
- Implement optical resonators to recycle the light before the wall and to boost the re-conversion of ALPs to photons behind the wall.
- The maximal length is given by the aperture of the magnets and the beam shape of the resonating mode in the optical resonators.
- The maximal circulating light power before the wall is given by the damage threshold of the mirrors and the beam spot size.

Present and future dipole magnets for LSW experiments

LSW experiments use dipoles developed for particle accelerators (and might use in future dipole magnets presently under development).

https://fcc.web.cern.ch/Pages/Magnets.aspx

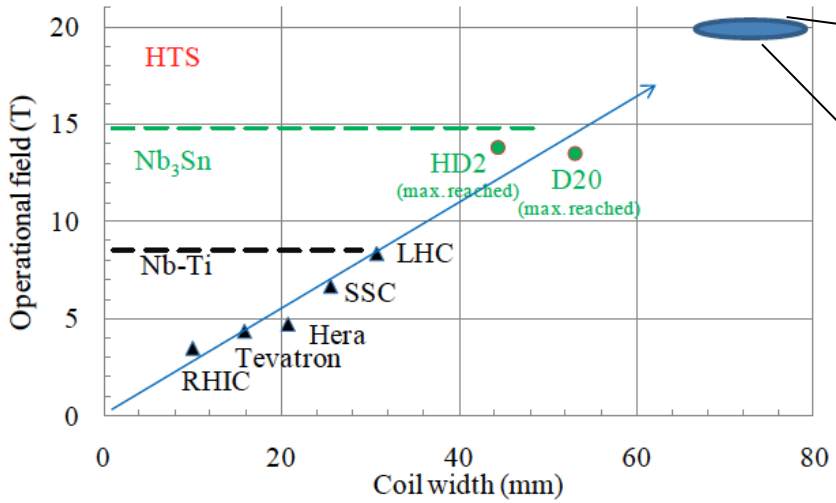


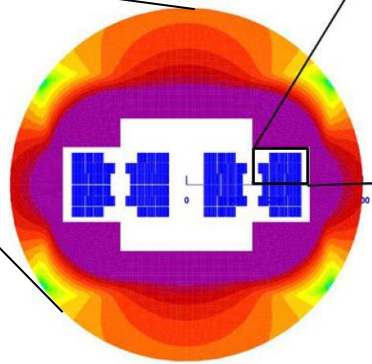
- OSQAR: LHC dipoles.
- ALPS II: HERA dipoles.

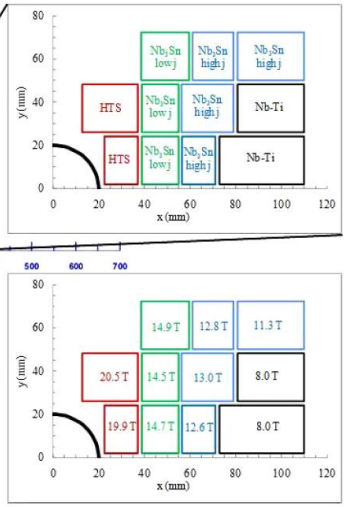
Present and future dipole magnets for LSW experiments

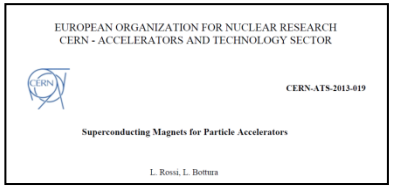
LSW experiments use dipoles developed for particle accelerators (and might use in future dipole magnets presently under development).

https://fcc.web.cern.ch/Pages/Magnets.aspx








EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN - ACCELERATORS AND TECHNOLOGY SECTOR

CERN-ATS-2013-019

Superconducting Magnets for Particle Accelerators

L. Rossi, L. Bottura

https://fcc.web.cern.ch/Documents/Publications/Magnets/CERN-ATS-2013-019.pdf

- Thereafter one (or more) of these magnet designs may be produced in small series and become available for LSW experiments.
- Depending of unit length, some 30-40 units may be needed for a 500 m long magnet string.

Present and future dipole magnets for LSW experiments

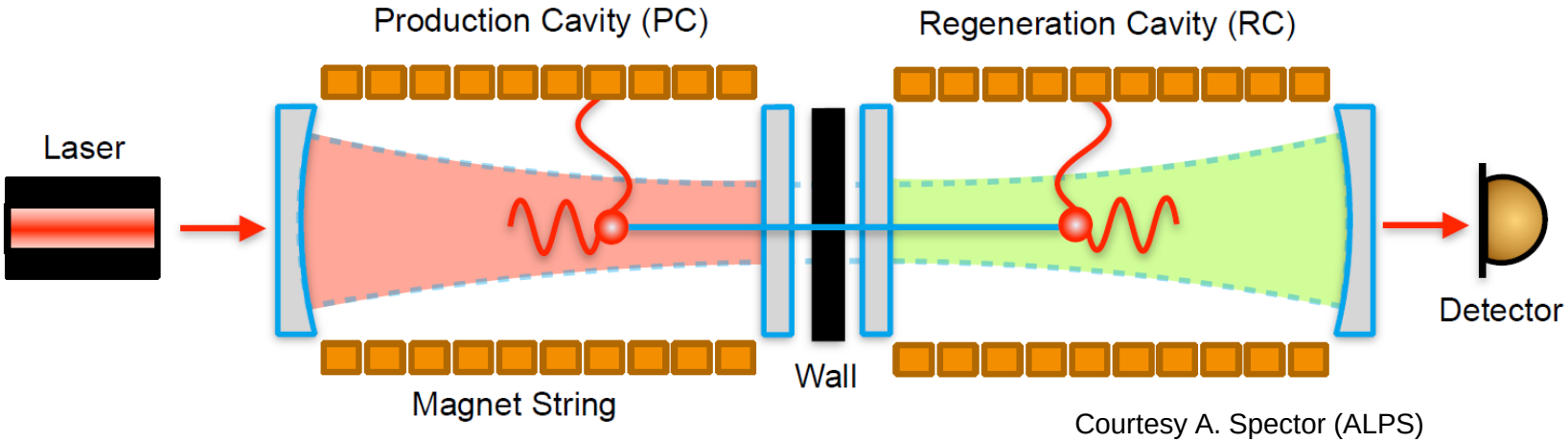
LSW experiments use dipoles developed for particle accelerators (and might use in future dipole magnets presently under development).

Dipole	Aperture [mm]	Field strength [T]	LSW experiment	Number of used dipoles
HERA (straightened)	50	5.3	ALPS II (DESY)	20
LHC	40	9.0	OSQAR (CERN)	2
“FCC”	100	13	“ALPS III”	

For the “FCC” dipole parameters see for example:

- Bottura L, de Rijk G, Rossi L, Todesco E., IEEE Trans. Appl. Supercond. 22:4002008 (2012), http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6656892
- Todesco E, Bottura L, de Rijk G, Rossi L., IEEE Trans. Appl. Supercond. 24:4004306 (2014), http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6172724

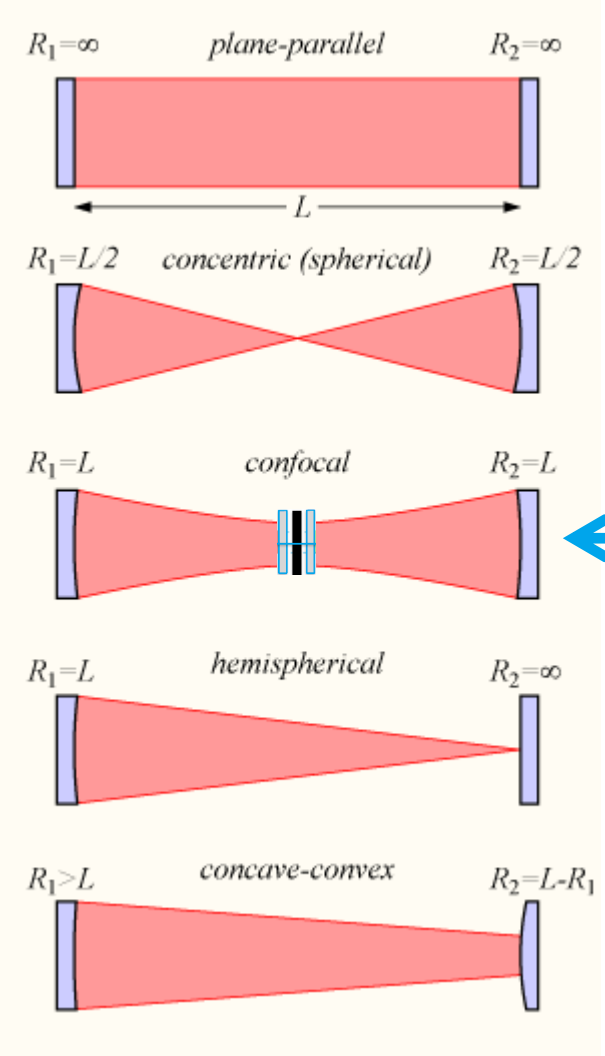
Optical resonators in LSW experiments



The resonators before and after the wall have to resonate to the same mode.

- Flat mirrors are placed in the center of the experiment around the wall.
- The light power density is highest on the flat mirror before the wall (mirror damage threshold)!

Optics for LSW experiments I: resonator configuration



https://en.wikipedia.org/wiki/Optical_cavity

A confocal cavity:

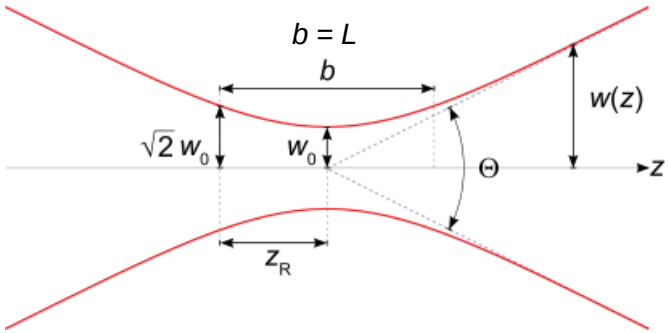
- longest resonator for a given aperture,
- largest beamspot in the center and hence lowest power density on central mirror, therefore highest circulating power in the resonator before the wall.

Gaussian beam in a confocal resonator

Using:

- L: length of the optical system, length of each resonator L/2.
- λ: wavelength of light

- Beam waist: $(\omega_0)^2 = (L \cdot \lambda) / 2\pi$
- Beam profile development:
  $\omega^2(z) = (\omega_0)^2 \cdot (1+(z/z_R)^2)$,
  $z_R = \pi(\omega_0)^2 / \lambda$
  $\omega(L/2) = \text{sqrt}(2) \cdot \omega_0$



https://en.wikipedia.org/wiki/Gaussian_beam

- Clear aperture required for a cavity with a power built-up ≈ 100,000:
  $r_5 = 2.5 \cdot \omega(z)$

Optics for LSW experiments II: resonator examples

Aperture [mm]	Safety margin [mm]	Eff. aperture [mm]	ω (L/2) [mm]	ω_0 [mm]	λ [nm]	L [m]
40 (LHC)	10	30	6.0	4.2	1064	106
50 (HERA)	10	40	8.0	5.7	1064	189
100 (FCC)	10	90	18.0	12.7	1064	957

- λ = 1064 nm is assumed following LIGO experience:
  mirror coatings for this wavelength can stand high power densities for long times.

Optics for LSW experiments II: resonator examples

Aperture [mm]	Safety margin [mm]	Eff. aperture [mm]	ω (L/2) [mm]	ω_0 [mm]	λ [nm]	L [m]	Maximal power [kW]	Magnetic length, one string [m]
40 (LHC)	10	30	6.0	4.2	1064	106	280	43
50 (HERA)	10	40	8.0	5.7	1064	189	500	81
100 (FCC)	10	90	18.0	12.7	1064	957	2500	426

- λ = 1064 nm is assumed following LIGO experiences:
  mirror coatings for this wavelength can stand high power densities for long times.
- For the maximal power assume a damage threshold of 500 kW/cm^2.
- For the magnetic length
  - subtract 10 m for the optical system outside the magnets and
  - assume a “filling factor” for the magnetic field of 90%.

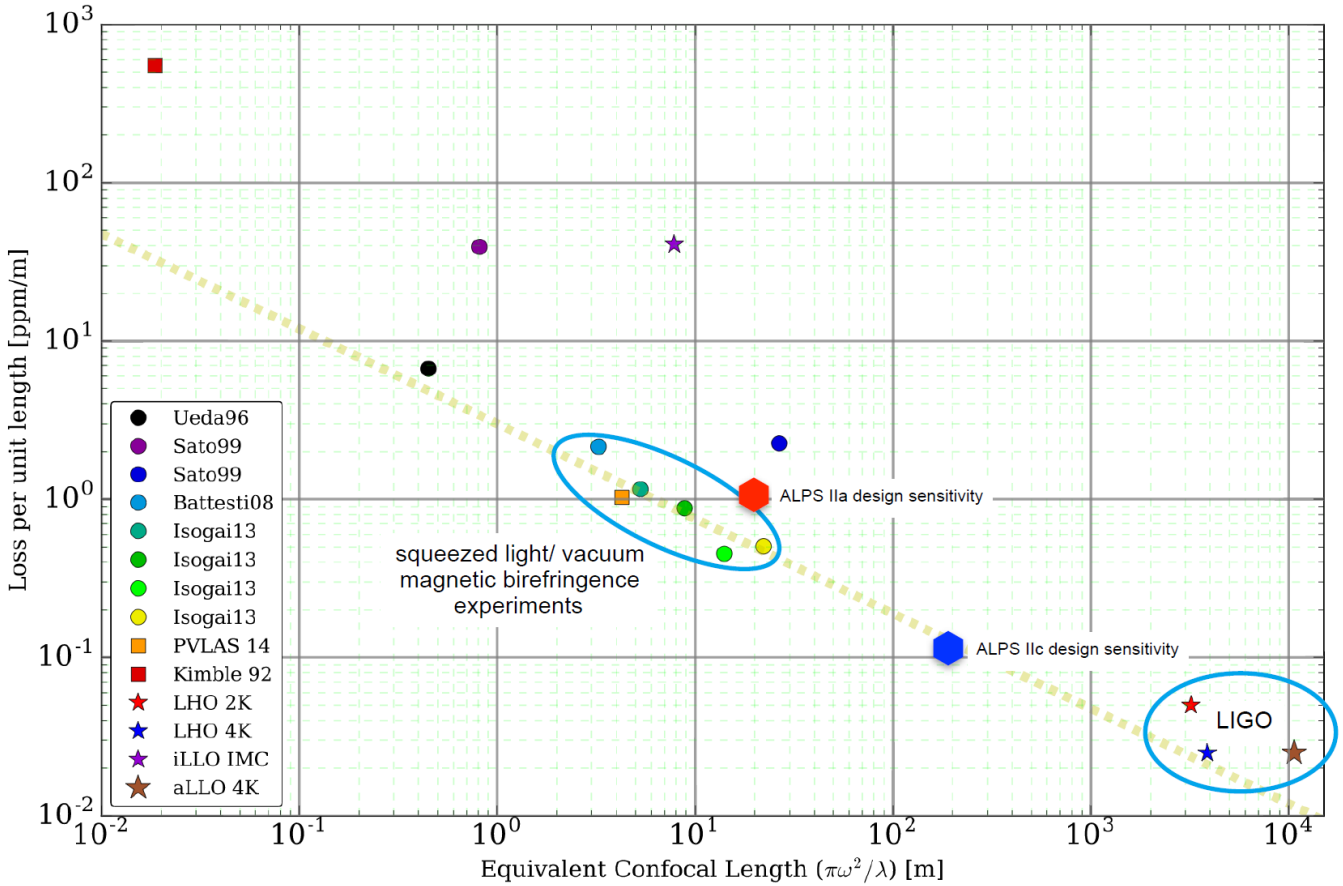
Optics for LSW experiments III: 532 nm options

Aperture [mm]	Safety margin [mm]	Eff. aperture [mm]	ω (L/2) [mm]	ω_0 [mm]	λ [nm]	L [m]	Maximal power [kW]	Magnetic length, one string [m]
50 (HERA)	10	40	8.0	5.7	1064	189	500	81
100 (FCC)	10	90	18.0	12.7	1064	957	2500	426
50 (HERA)	10	40	8.0	5.7	532	378	?	166
100 (FCC)	10	90	18.0	12.7	532	1913	? · 5	856

- If high power, high quality mirror coatings for λ = 532 nm were available, LSW experiments could be doubled in length compared to λ = 1064 nm.
- R&D is required to improve the power density damage threshold of coatings for 532 nm light.

Challenges in optics

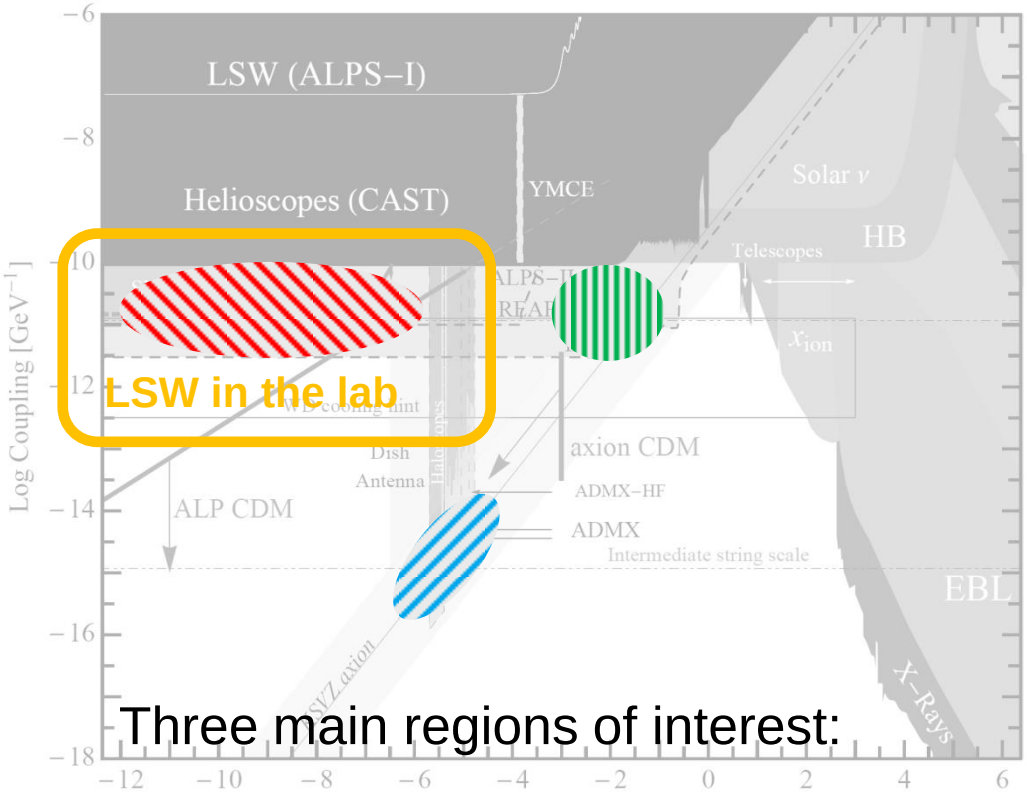
- Minimal losses: key parameter for the regeneration cavity! ALPS II at DESY is “cutting edge” optics.

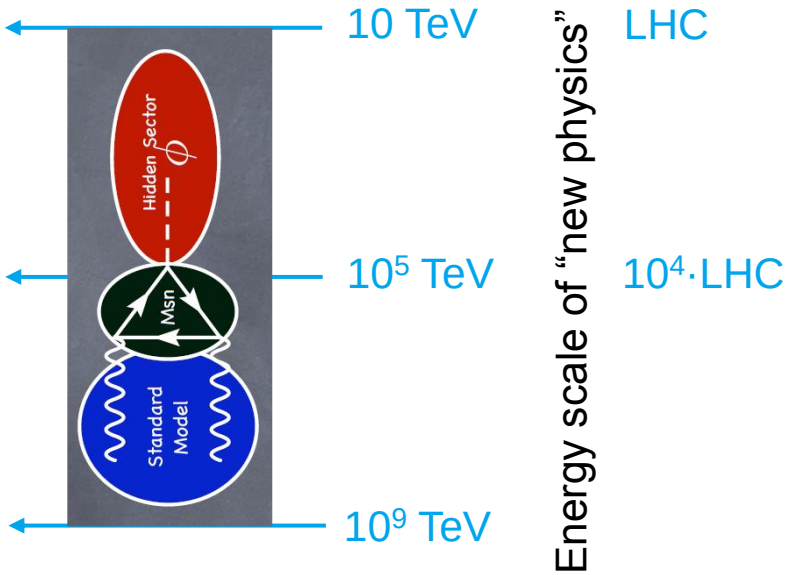


Courtesy J. Põld, A. Spector (ALPS II)

plot from LIGO T-1400226-v6

A LSW roadmap: Axions and axion-like-particles (ALPs)



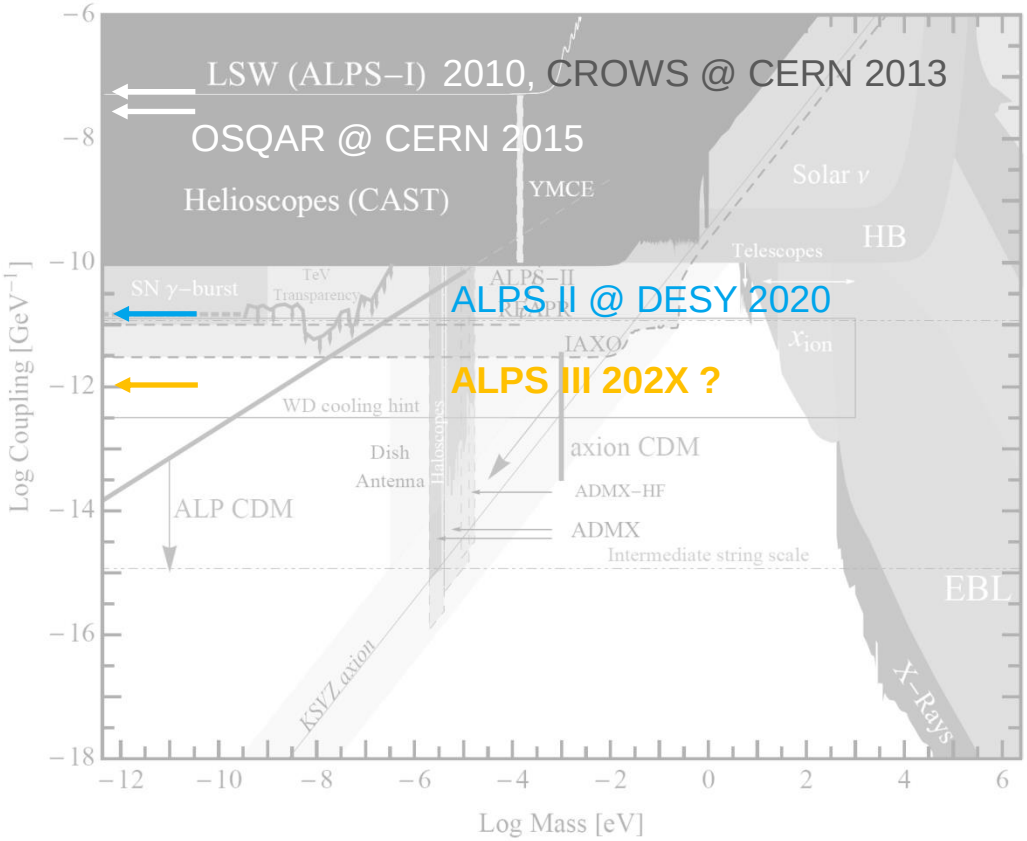


Three main regions of interest:

- Axion-like particles: "new physics" around 10^5 TeV.
- QCD axions: "new physics" around 10^5 TeV.
- QCD axions as dark matter: "new physics" around 10^9 TeV.

Stellar develop., TeV transp.

A LSW roadmap: Axions and axion-like-particles (ALPs)



- Improve on the ALPS-photon-photon coupling strength g by > 1,000.

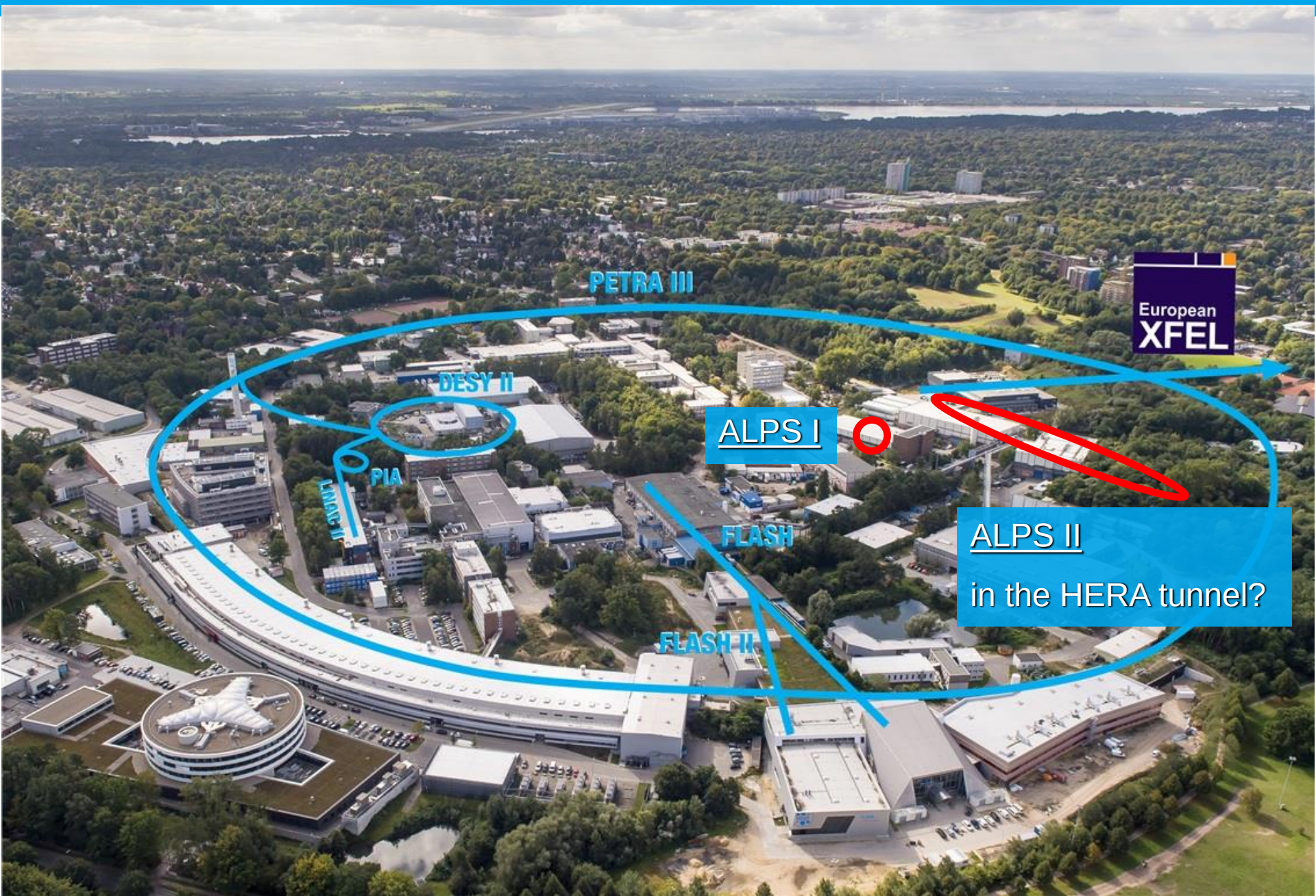
The experiment measures a rate ~ g^4:

- The experimental sensitivity is to increased by a factor 10^{12}!

Outline

- Motivation for purely laboratory based efforts to find Weakly Interacting Slim Particles
- ALP / axion searches via photon couplings
- Light-shining-through-a-wall: ALPS II and beyond
- 5th force searches
- Summary

AnyLightParticleSearch (ALPS) @ DESY in Hamburg

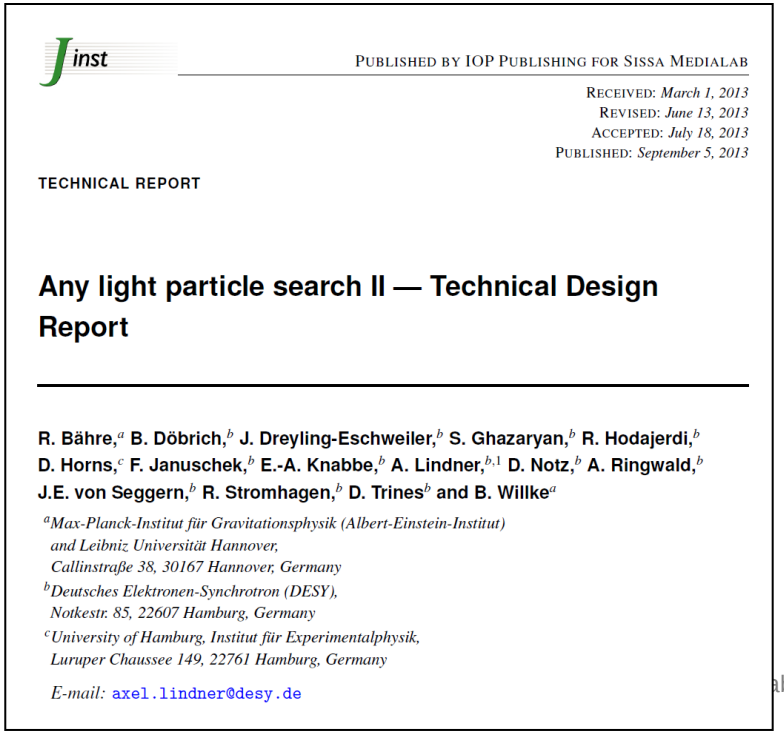


ALPS @ DESY

ALPS I:
approved 2007,
concluded 2010.

ALPS @ DESY

ALPS I:
approved 2007,
concluded 2010,
most sensitive WISP search experiment in the lab (up to 2014).



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TECHNICAL REPORT

Any light particle search II — Technical Design Report

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[b]*Deutsches Elektronen-Synchrotron (DESY), Notkestr. 85, 22607 Hamburg, Germany*
[c]*University of Hamburg, Institut für Experimentalphysik, Luruper Chaussee 149, 22761 Hamburg, Germany*

E-mail: axel.lindner@desy.de

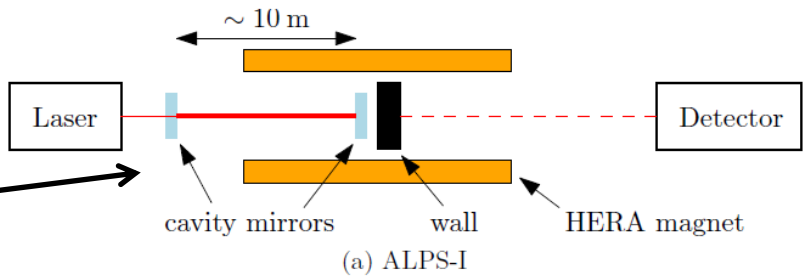
R Bähre *et al* 2013 *JINST* **8** T09001

ALPS II:
targeting mainly axion-like particles,
proposed 2011,
TDR finished and evaluated in 2012.

Decision by the directorate:
continue with the preparatory phase towards ALPS II.

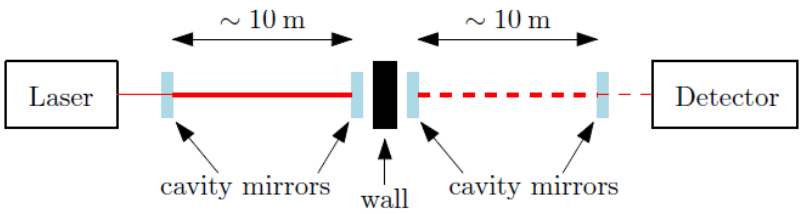
ALPS II is realized in stages (JINST 8 (2013) T09001)

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



(a) ALPS-I

> **ALPS IIa**



(b) ALPS-IIa

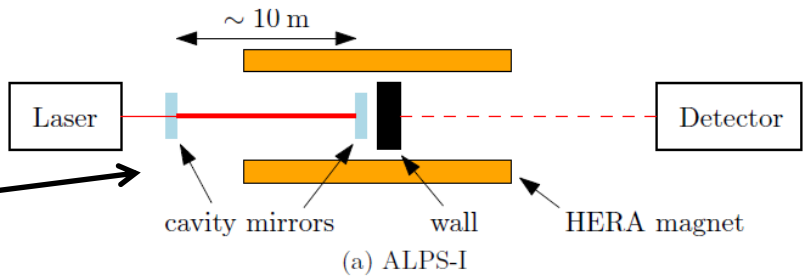
Optical resonator to increase effective light flux by recycling the laser power

Optical resonator to increase the conversion probability

WISP→γ

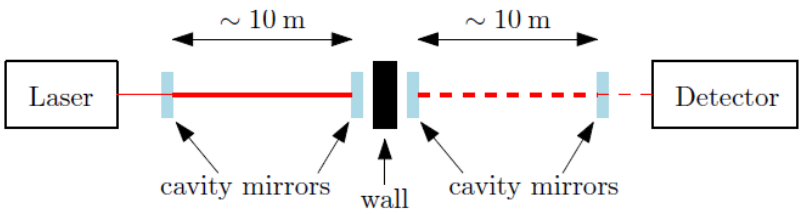
ALPS II is realized in stages (JINST 8 (2013) T09001)

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



(a) ALPS-I

> **ALPS IIa**



(b) ALPS-IIa

The optics concept was invented three times independently:

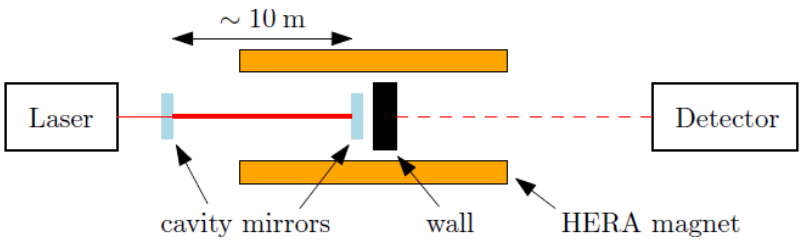
- *Hoogeveen F, Ziegenhagen T. Nucl. Phys. B358:3 (1991)*
- *Fukuda Y, Kohmoto T, Nakajima Si, Kunitomo M. Prog. Cryst. Growth Charact.Mater. 33:363 (1996)*
- *Sikivie P., Tanner D.B., van Bibber K. Phys.Rev.Lett. 98 (2007)*

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

Optical resonator to increase the conversion probability WISP→γ

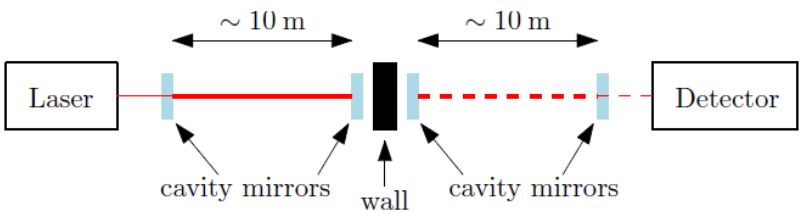
ALPS II is realized in stages (JINST 8 (2013) T09001)

ALPS I



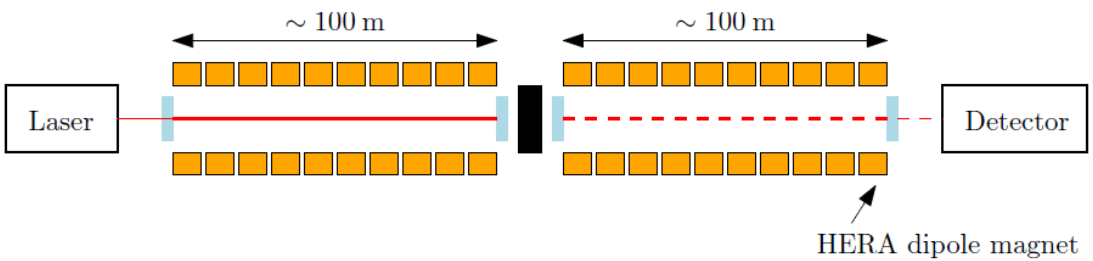
(a) ALPS-I

> **ALPS IIa**



(b) ALPS-IIa

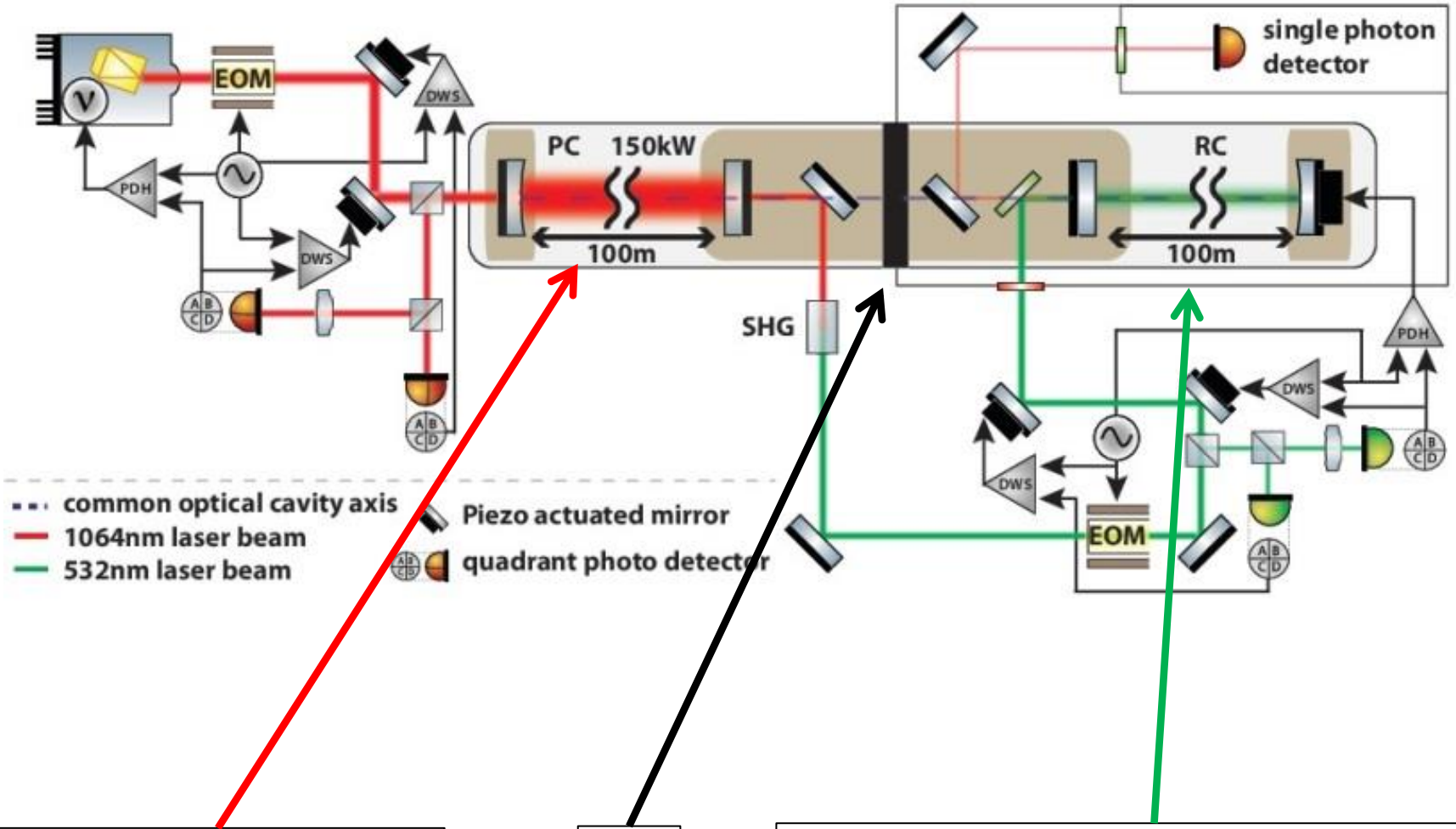
> **ALPS IIc**



(d) ALPS-IIc

20 HERA dipoles, 200 m long

ALPS II optics: two mode-matched optical cavities

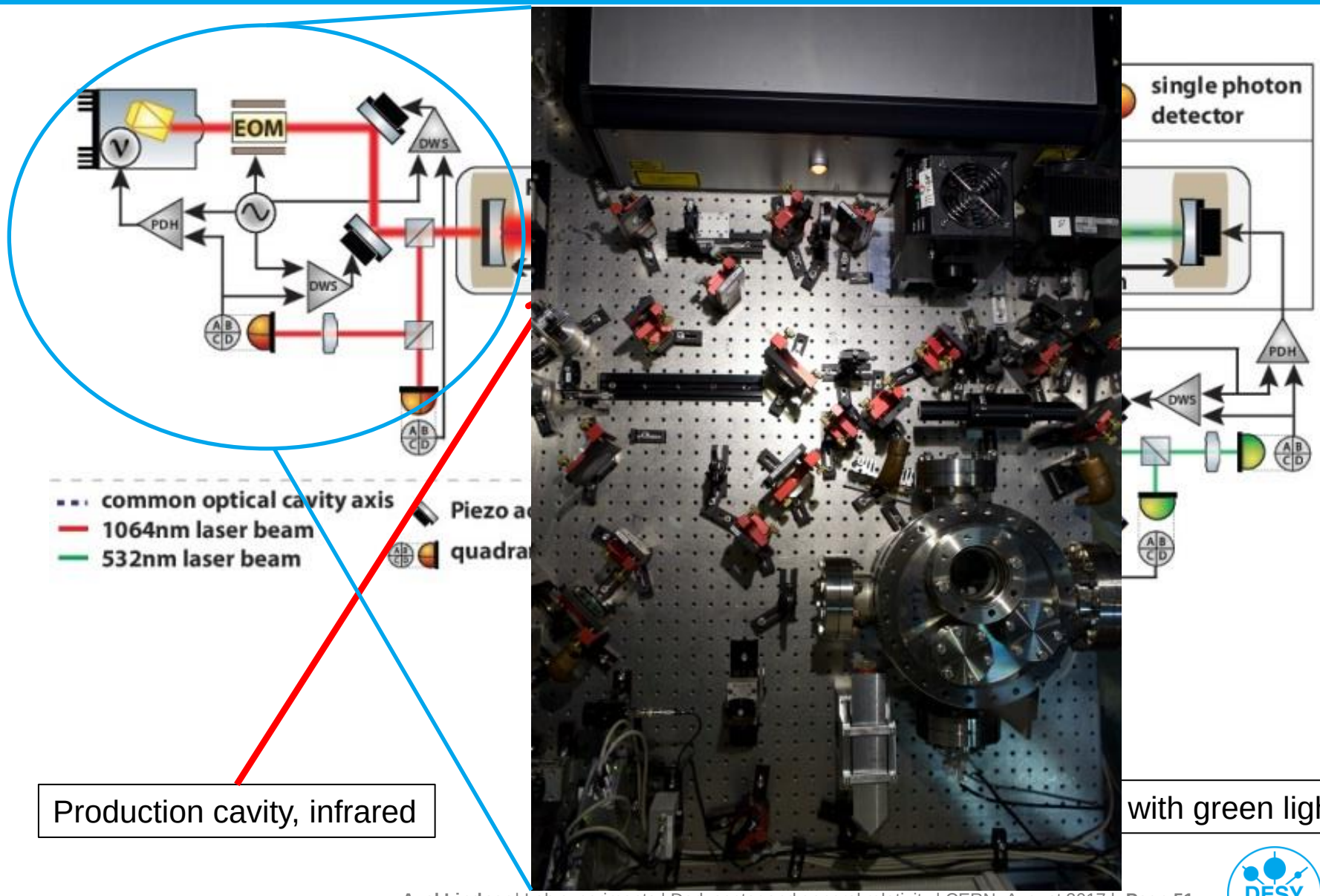


Production cavity, infrared

Wall

Regeneraton cavity, locked with green light.

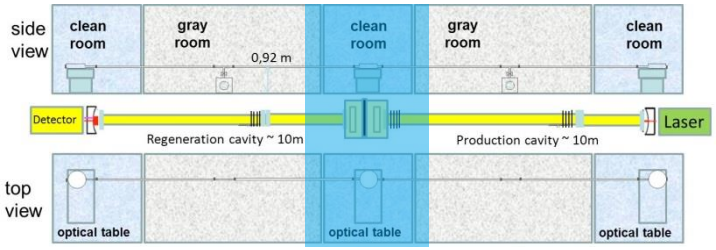
ALPS II optics: two mode-matched optical cavities

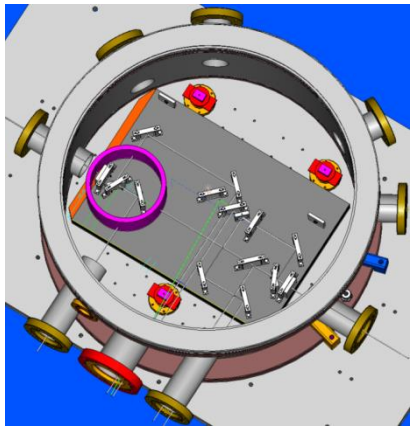


Production cavity, infrared

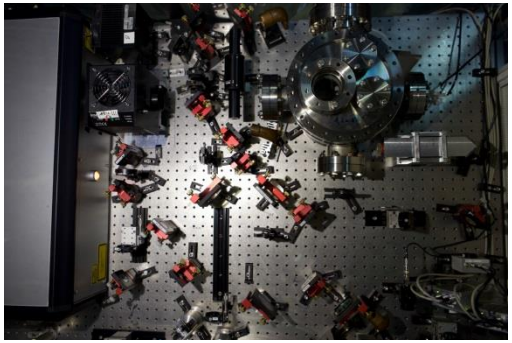
with green light.

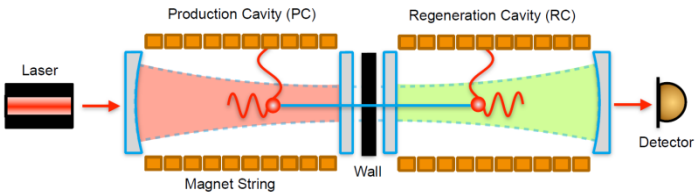
The central optics





ALPS II: optics





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Optics EXPRESS

Characterization of optical systems for the ALPS II experiment

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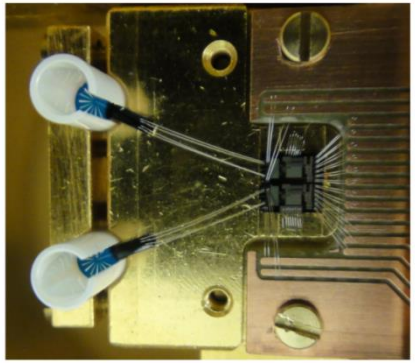
*aaron.spector@desy.de

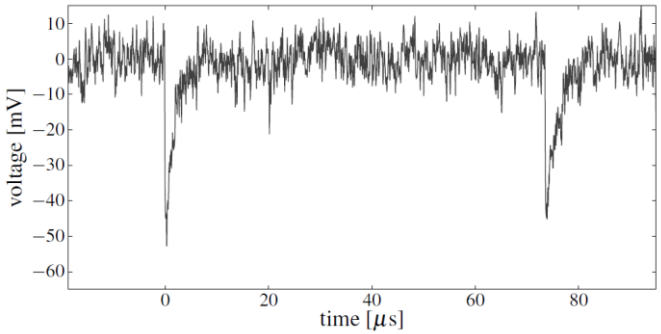
Parameter	Goal	Achieved	Comment
Power-built up PC	5,000	4,000	Extra losses 77 ppm
Power in PC	150 kW	50 kW	Thermal effects on mirrors
Power-built up RC	40,000	14,000	Extra losses 55 ppm
Mirror alignment	5 µrad	< 1 µrad	
PC-RC spat. overlap	> 95%		Work ongoing
RC length stabilization	< 0.5 pm		Work ongoing
RC dual color lock			Work ongoing

Two ALPS II detector options (to convince everyone …)

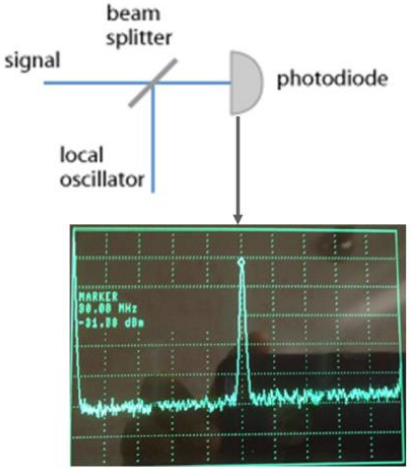
- Transition Edge Sensor (TES) for photon counting:

module with two channels
(scale ~ 3cm x 3cm)

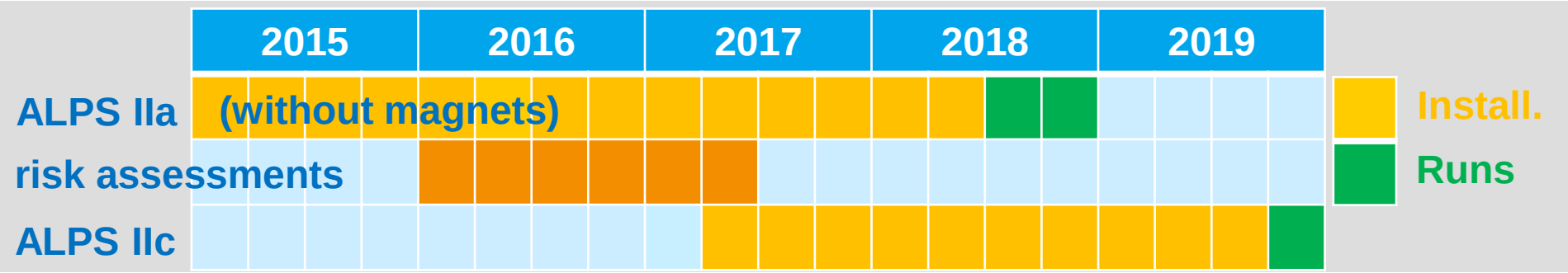




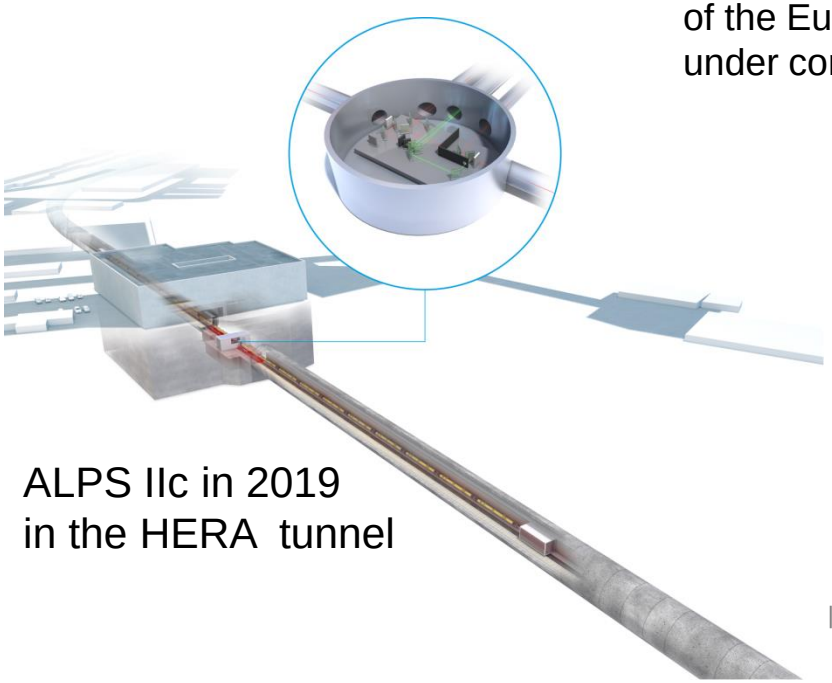
- Heterodyne detection scheme: mix light from ALPs with light at a slightly shifted frequency and look for a signal at the beat frequency.



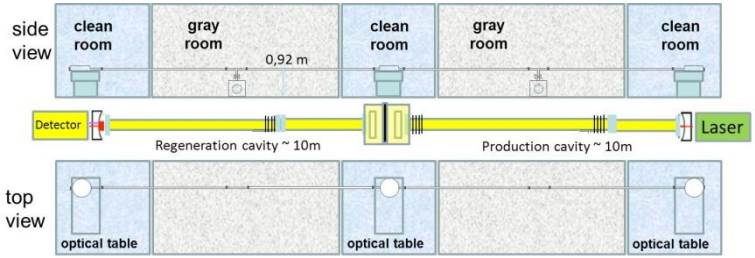
ALPS II schedule (rough)



Closure of the LINAC tunnel of the European XFEL under construction at DESY.



ALPS IIc in 2019
in the HERA tunnel



The ALPS II collaboration

ALPS II is a joint effort of

- DESY,
- AEI Hannover (MPG & Hannover Uni.),
- Mainz University,
- University of Florida (Gainesville)

with strong support from

- neoLASE, PTB Berlin, NIST (Boulder).

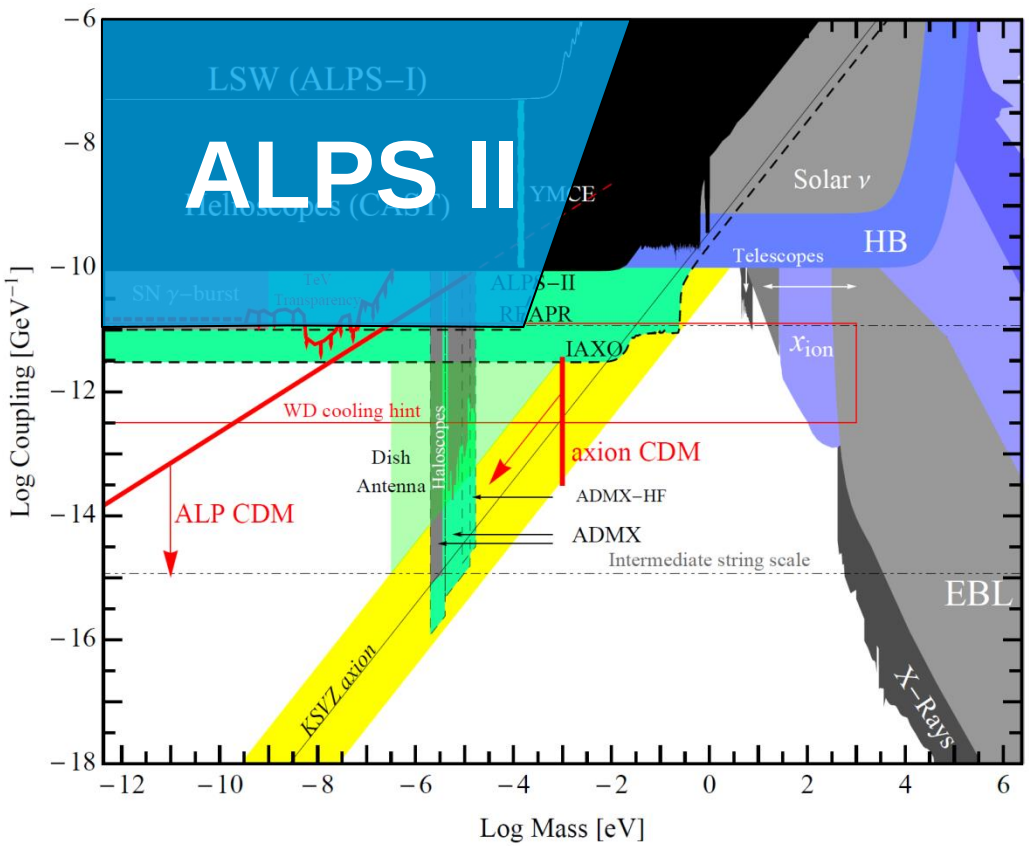
ALPS II sensitivity

- Well beyond current limits.
- Aim for data taking in 2020.

- QCD axions not in reach.
- Able to probe hints from astrophysics.

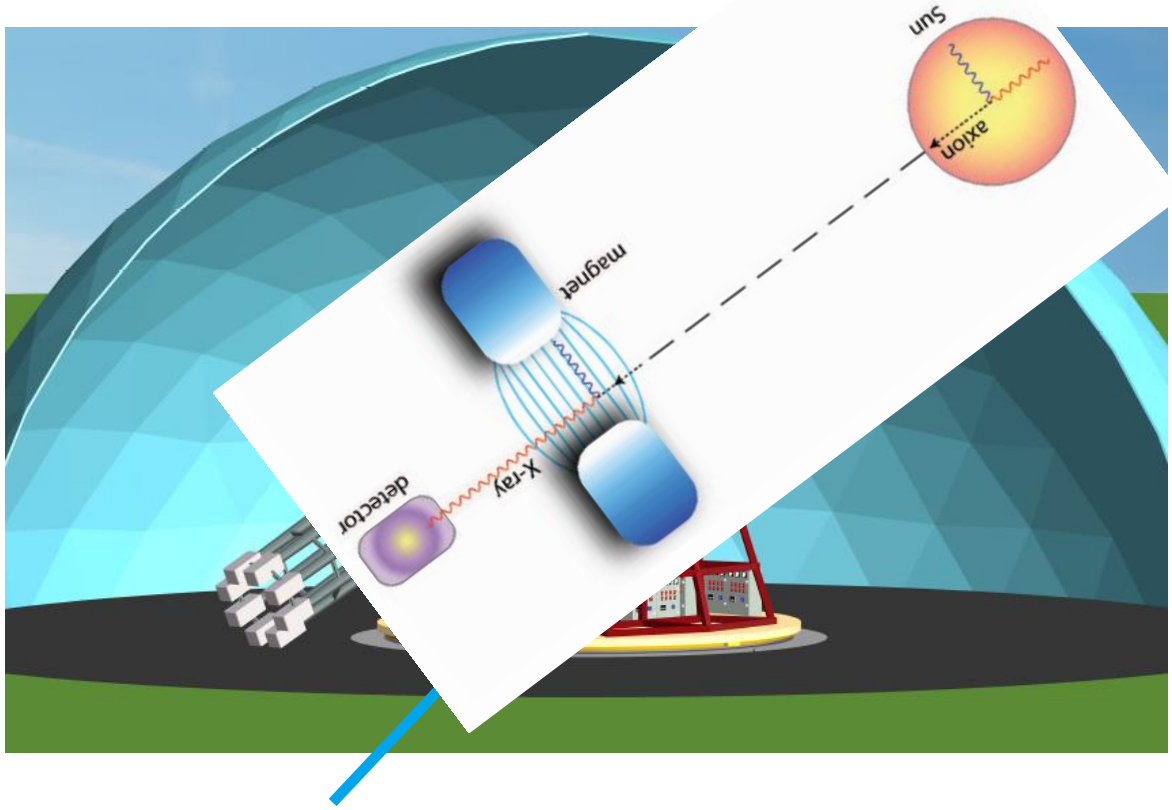
- Need IAXO or “ALPS III” to fully exclude the ALP-explanation of the astrophysics hints.

ALPS II:O(2 M€)
IAXO: O(60 M€)



Excursus: the International Axion Observatory

- IAXO is proposed by scientists out of 38 institutes from 9 countries.
  - CAST principle with dramatically enlarging the aperture
  - Use of toroid magnet similar to ATLAS @ LHC
  - X-ray optics similar to satellite experiments.



Conceptual Design of the International Axion Observatory (IAXO): JINST 9 (2014) T05002

IAXO "founding" meeting at DESY, July 2017: https://indico.cern.ch/event/622974/overview

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Future lessons to be learned from ALPS II

- The optics and detector design should be ready by the end of 2018.
- At present we are optimistic to reach (or come close) to our specs.
- Most likely the performance will be “budget limited”.
- We should know in late 2018 how one could further improve if the available budget increases from O(1 M€) to O(10 M€).

ALPS II could show the path to
“ultimate optics and detector concepts”
for laser driven LSW experiments.

But new magnets are required for further jumps in sensitivity!

Ingredients for an “ALPS III” experiment

An “ALPS III” sketch:

> Magnetic field strength:	13 T	(“FCC”)
> Magnetic length:	426 m	
> Light wavelength:	1064 nm	(“standard”)
> Circulating light power:	2.5 MW	
Photons against the wall:	$1.4 \cdot 10^{25}$ s^{-1}	
> Power built-up behind the wall:	10^5	
> Detector sensitivity:	10^{-4} s^{-1}	(“demonstrated”)

Ingredients for an “ALPS III” experiment

An “ALPS III” sketch:

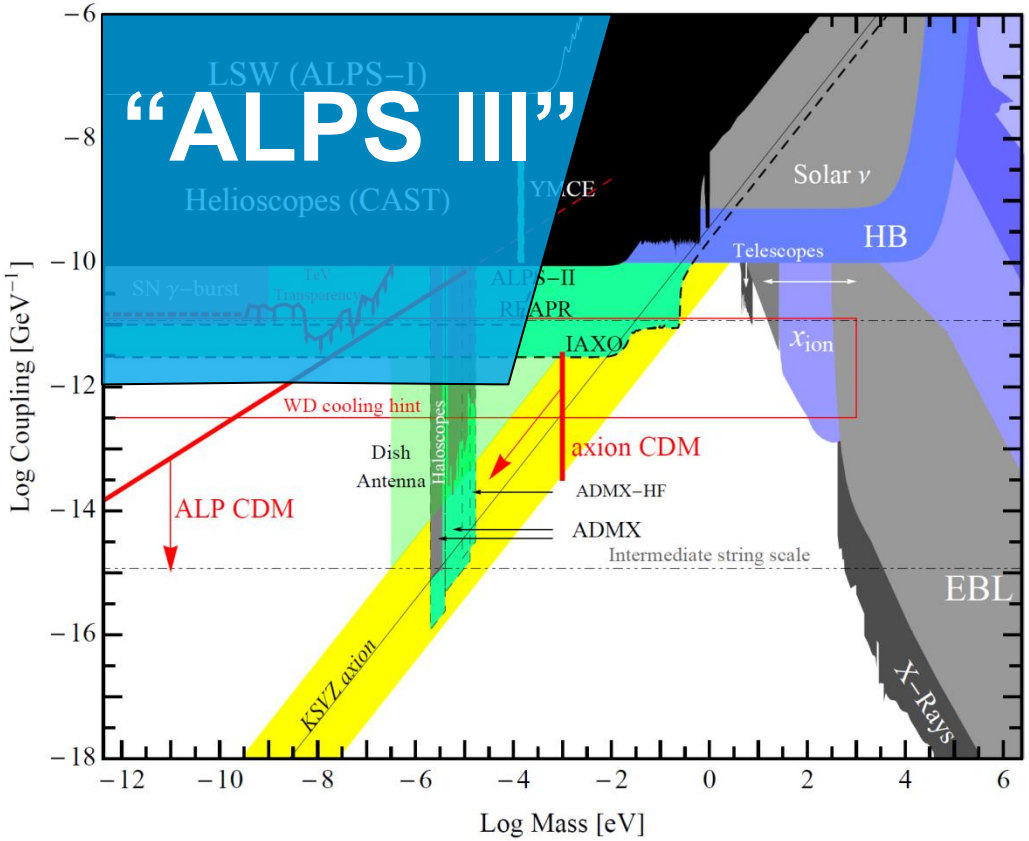
		sensitivity gain / ALPS II
> Magnetic field strength:	13 T	2.5
> Magnetic length:	426 m	4.8
> Light wavelength:	1064 nm	
> Circulating light power:	2.5 MW	2.0
Photons against the wall:	$1.4 \cdot 10^{25}\ s^{-1}$	
> Power built-up behind the wall:	10^{5}	1.3
> Detector sensitivity:	$10^{-4}\ s^{-1}$	1.0

> **Improving the sensitivity for $g_{a\gamma}$ compared to ALPS II by 2.5·4.8·2.0·1.3·1.0 = 30**

“ALPS III” in context

“ALPS III”

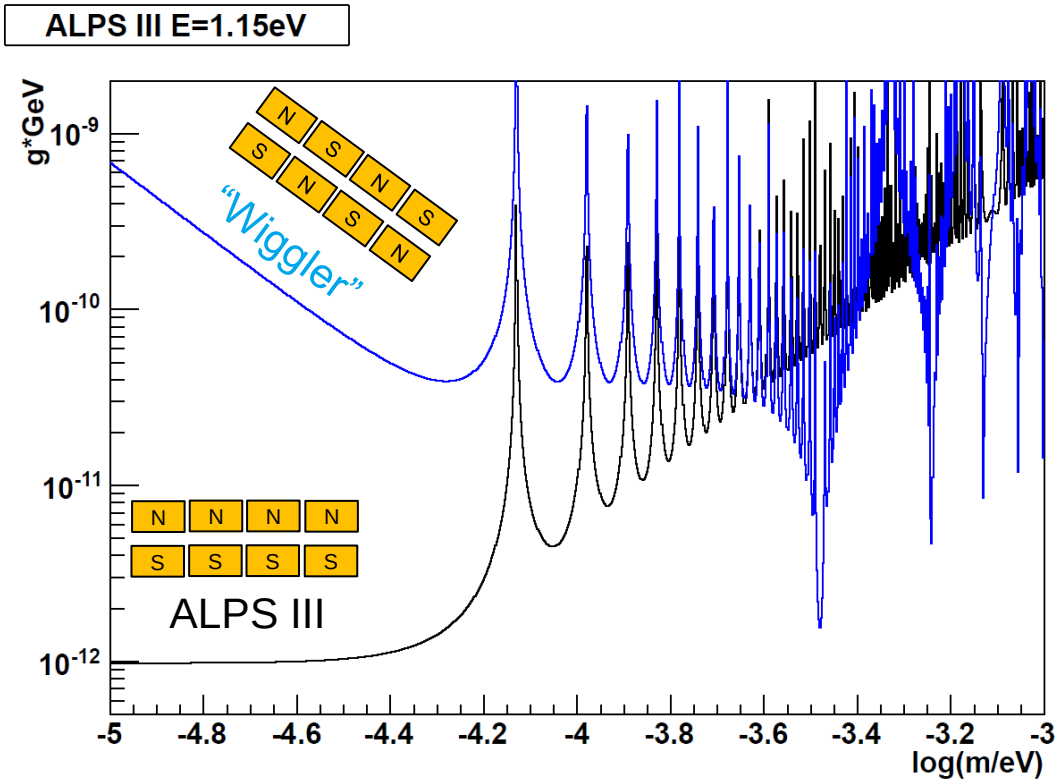
- would dramatically increase the sensitivity for purely laboratory based experiments searching for axion-like particles.
- would surpass even IAXO for very low mass ALPs.
- would definitely probe astrophysics hints for ALPs.
- would probe “dark matter” ALPs.
- would perfectly complement IAXO!



A little bonus

Assume to realize both magnet strings out of 40 dipoles each and

- switch polarity between each dipole ("wiggler configuration"):



The full sensitivity is restored at a specific mass!

Just for the fun of it: a little QCD axion bonus …

"ALPS III"

- would dramatically increase the sensitivity for purely laboratory based experiments searching for axion-like particles.
- would surpass even IAXO for very low mass ALPs.
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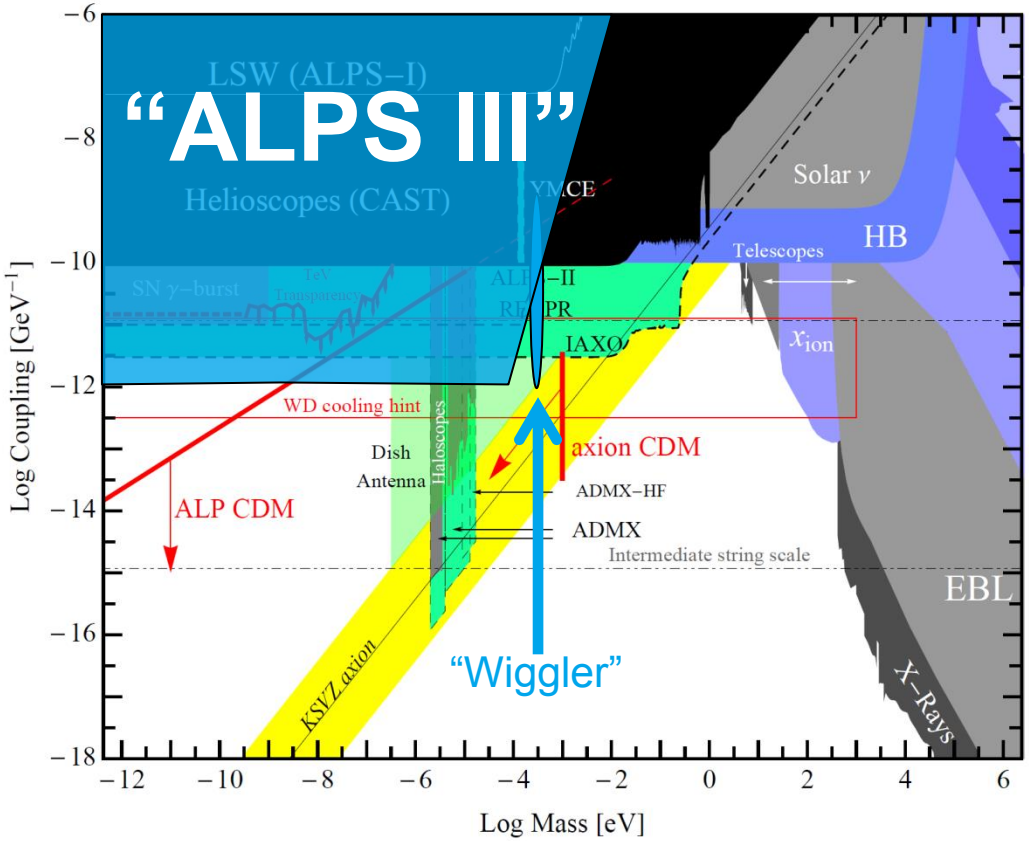


Outline

- Motivation for purely laboratory based efforts to find Weakly Interacting Slim Particles
- ALP / axion searches via photon couplings
- Light-shining-through-a-wall: ALPS II and beyond
- 5th force searches
- Summary

Fifth force mediated by ALPs / axions?

The coupling to nucleons and / or fermions could result in a fifth force:

- Look for spin-dependent forces.
- Range given by the axion mass $\lambda_a = \frac{\hbar c}{m_a}$.

The challenge:

- Need to increase the sensitivity of existing experiments by eight orders of magnitude to access axions in the mass range 10^{-6} to 10^{-3} eV (100 µm to 10 cm).

Resonant detection of axion mediated forces with Nuclear Magnetic Resonance

Asimina Arvanitaki[1], Andrew A. Geraci[2]
[1] *Perimeter Institute for Theoretical Physics, Waterloo, ON N2L 2Y5, Canada and*
[2] *Department of Physics, University of Nevada, Reno, NV 89557, USA*
(Dated: March 7, 2014)

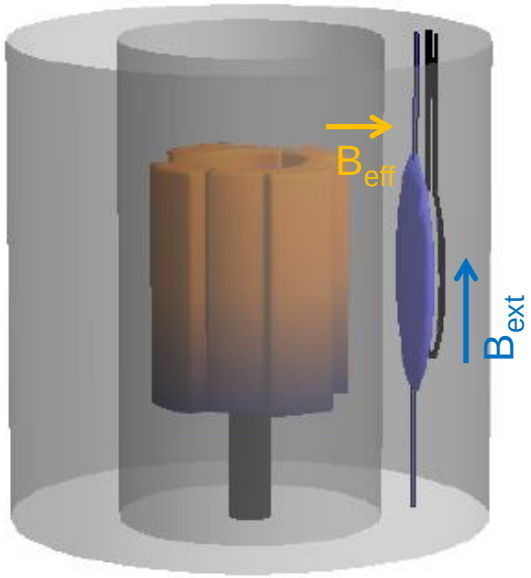
Phys. Rev. Lett. 113, 161801 (2014), https://arxiv.org/abs/1403.1290

Fifth force mediated by ALPs / axions?

Axion **R**esonant **I**nter**A**ction **D**etectio**N** **E**xperiment (ARIADNE)

- Under preparation at CAPP (Korea).

Phys. Rev. Lett. 113, 161801 (2014), https://arxiv.org/abs/1403.1290



Rotating source mass
induces an effective magnetic field B_{eff}.

NMR sample (^{3}He)
tuned to the resonance frequency by B_{ext}.

Superconducting shielding

- If in resonance, the NMR sample will built up a magnetization perpendicular to its polarization:

$$M(t) \approx \frac{\hbar}{2} n_s p \mu_N \gamma_N B_{\text{eff}} t \cos(\omega t)$$

Fifth force mediated by ALPs / axions?

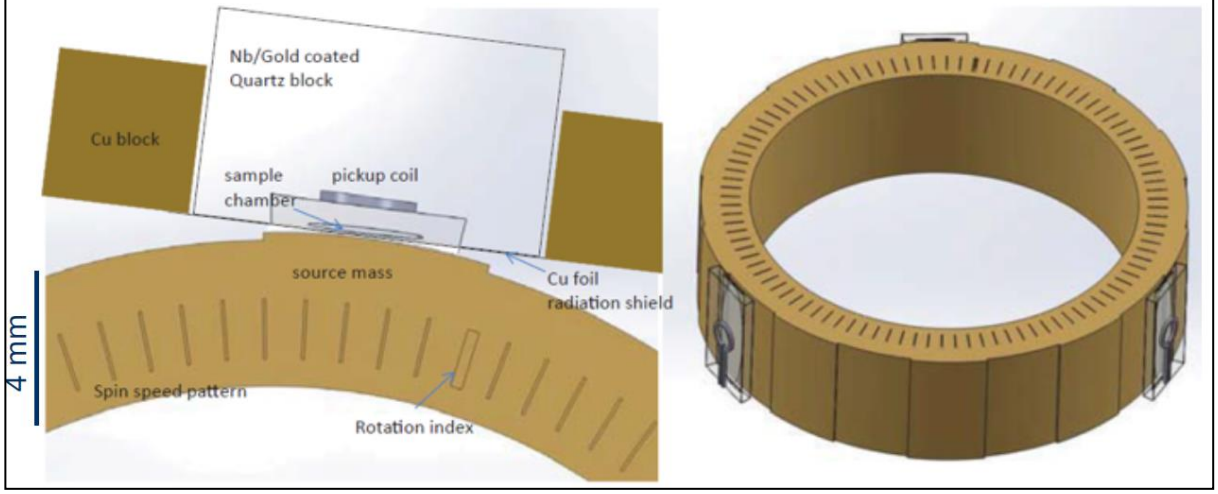
Axion **R**esonant **I**nter**A**ction **D**etectio**N** **E**xperiment (ARIADNE)

> Under preparation at CAPP (Korea).

Experimental parameters

11 segments
100 Hz nuclear spin precession frequency
2 x 10^{21} / cc ^{3}He density
10 mm x 3 mm x 150 µm volume
Separation 200 µm
Tungsten source mass (high nucleon density)

A. Geraci

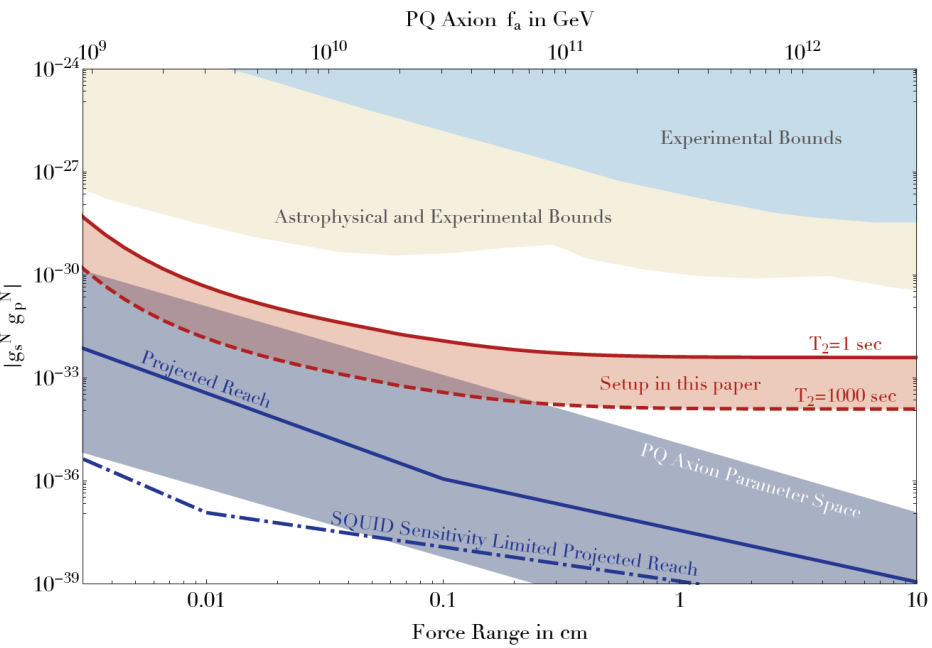


Bethe Forum Bonn, March 2916,
http://bctp.uni-bonn.de/bethe-forum/2016/axions/talks/Semertzidis.pdf

Fifth force mediated by ALPs / axions?

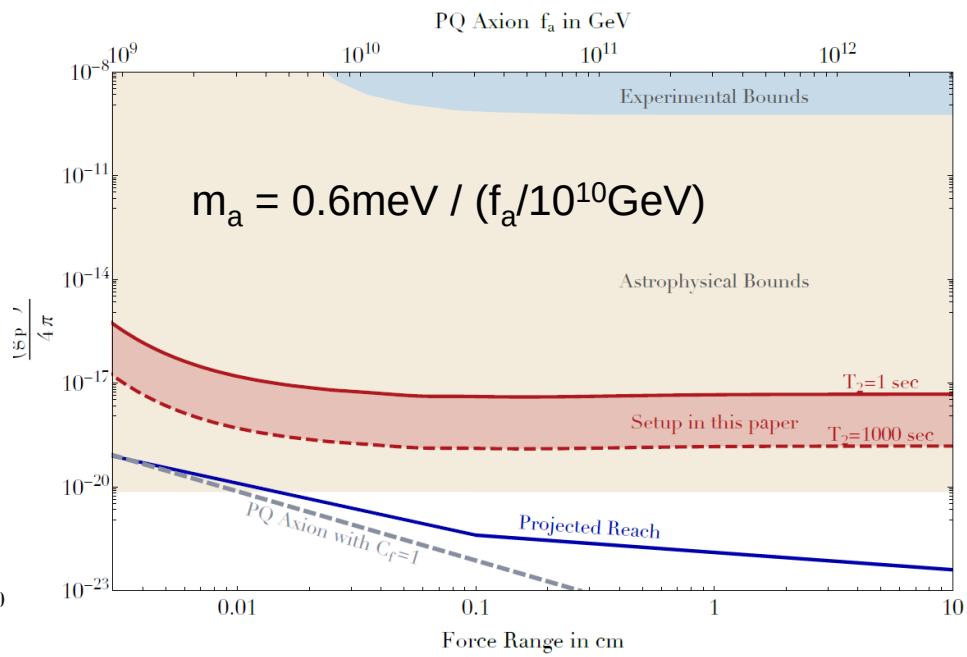
Axion **R**esonant **I**nter**A**ction **D**etectio**N** **E**xperiment (ARIADNE)

Monopole-dipole interaction with ^{3}He nuclei



QCD axions in reach, if CP violating interaction close to present limits from neutron EDM.

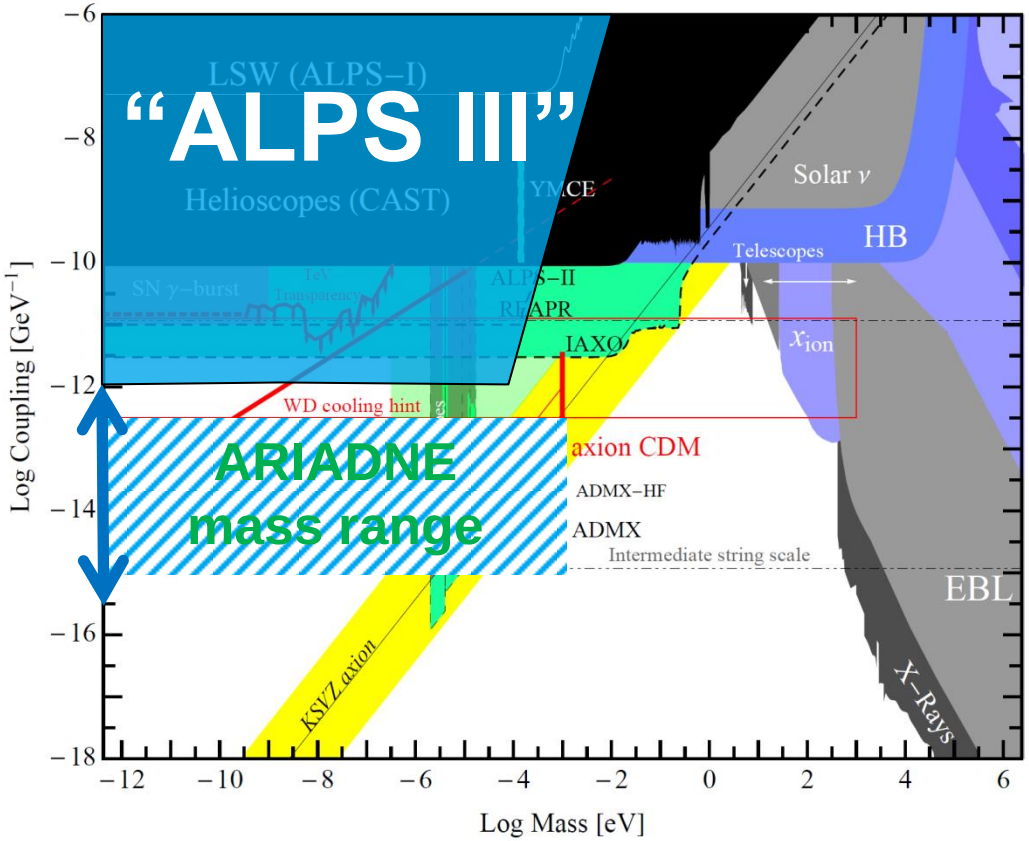
Dipole-dipole interaction with ^{3}He nuclei



Requires a spin-polarized source mass. Less model dependent, but hard to reach the QCD axion. Look for other targets?

Summary

- Purely laboratory based experiments probe the hidden sector without relying on astrophysical and cosmological assumptions.
- “Light-shining-through-a-wall’ will be able to probe for ALP-photon couplings as suggested by astrophysics hints.



- Spin-related 5th force experiments might reach the axion (model dependent).
- Do not forget about EDM searches.
- Future purely laboratory experiments deserve (and require) considerable effort!