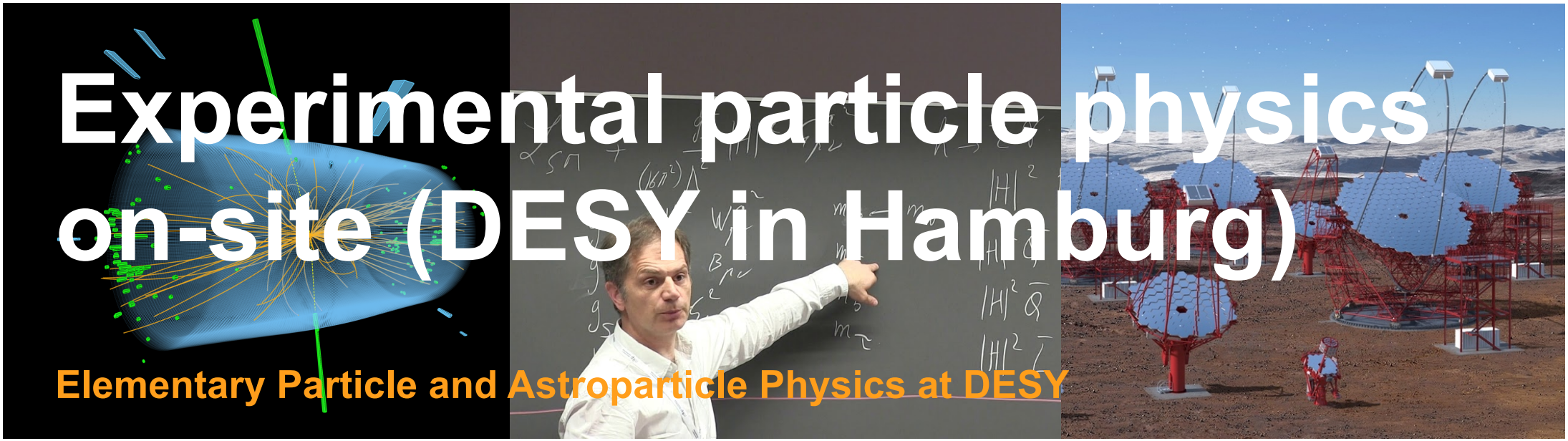


Experimental particle physics on-site (DESY in Hamburg)

Elementary Particle and Astroparticle Physics at DESY

Helmholtz Program: Matter and the Universe (MU)

PoF III Topic: Fundamental Particles and Forces

DESY Research Unit: Experimental Particle Physics

Axel Lindner
Center Evaluation DESY, 5 – 9 February 2018

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

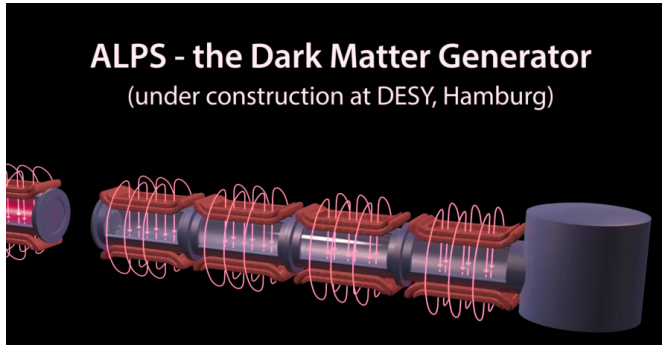
DESY

Experimental particle physics on-site (DESY in Hamburg)

Using infrastructure at DESY in Hamburg

- Approaching the dark sector via axion / axion-like particle experiments:

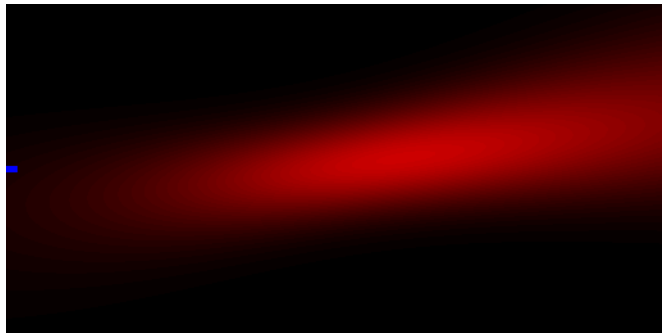
  ALPS II (under construction)
  MADMAX (under preparation)
  IAXO (under preparation)



Courtesy S. Barke,
UF postdoc at ALPS II

- Nonperturbative QED in strong fields with

  LUXE (feasibility study)



https://www.slac.stanford.edu/exp/e144/focpic/focpic.html

Introduction to axions and axion-like particles (ALPs)

Looking for an entrance to the dark sector

A dark sector beyond the Standard Model

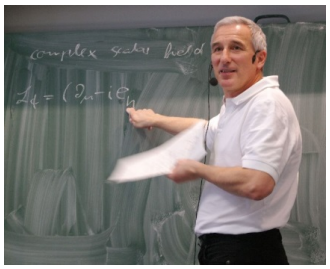
- is strongly motivated by cosmology,
- might be complex with several constituents.

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

Axions and axion-like particles

- are strongly motivated by theory (CP conservation in QCD)
- and cosmology (dark matter),
- might be starting to show up in astro(particle) physics already
  - excess radiation from stars,
  - transparency of the universe to TeV photons,

- offer new experimental approaches towards the dark sector,
  - strongly guided also from DESY theory.



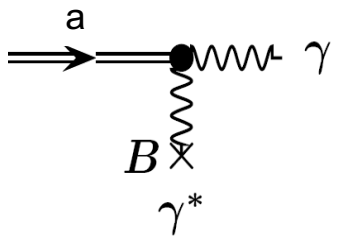
A. Ringwald,
also member of exp. collaborations.

Introduction to axions and axion-like particles (ALPs)

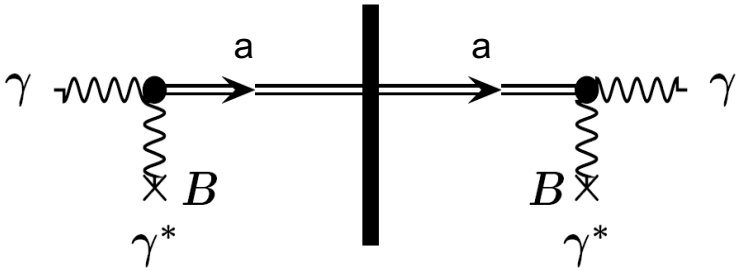
How to look: exploiting photon couplings

From conversion in a magnetic field …

Primakoff-like effect (Sikivie ‘83)



… to light-shining-through-a-wall

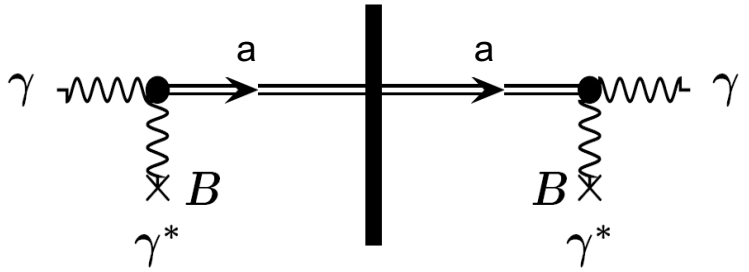


ALPS II: $P(\gamma \rightarrow a \rightarrow \gamma) \approx 10^{-36}$

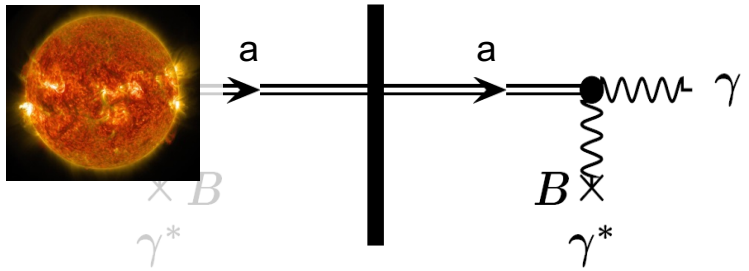
Introduction to axions and axion-like particles (ALPs)

How to look: three kinds of approaches

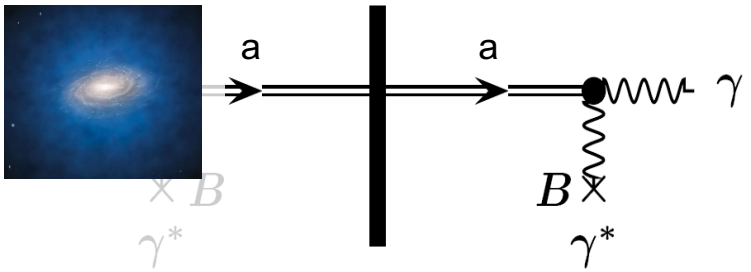
- Purely laboratory experiments
  “light-shining-through-walls”, optical photons, generation of ALPs in the lab.



- Helioscopes
  ALPs emitted by the sun, X-rays,

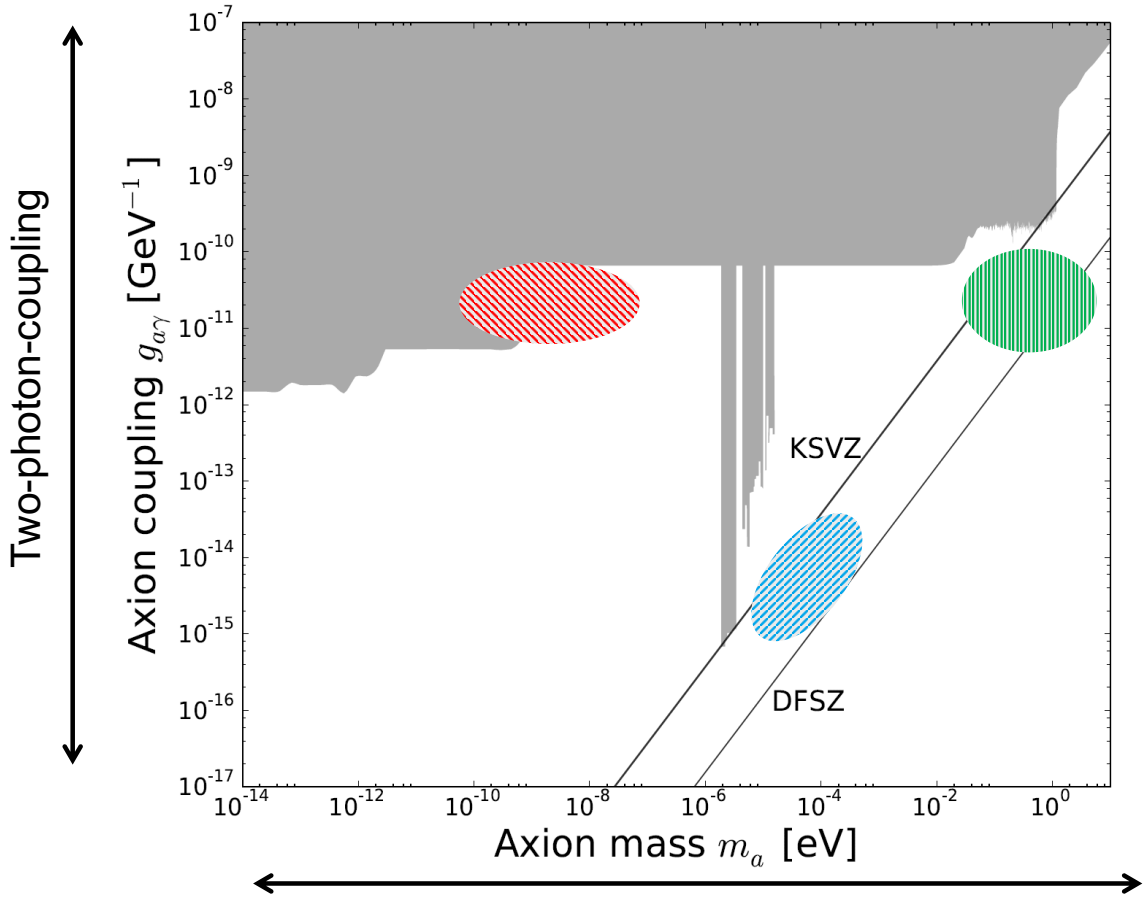


- Haloscopes
  looking for dark matter constituents, microwaves.



Introduction to axions and axion-like particles (ALPs)

Where to look: hot spots in parameter space



Three main regions of interest:

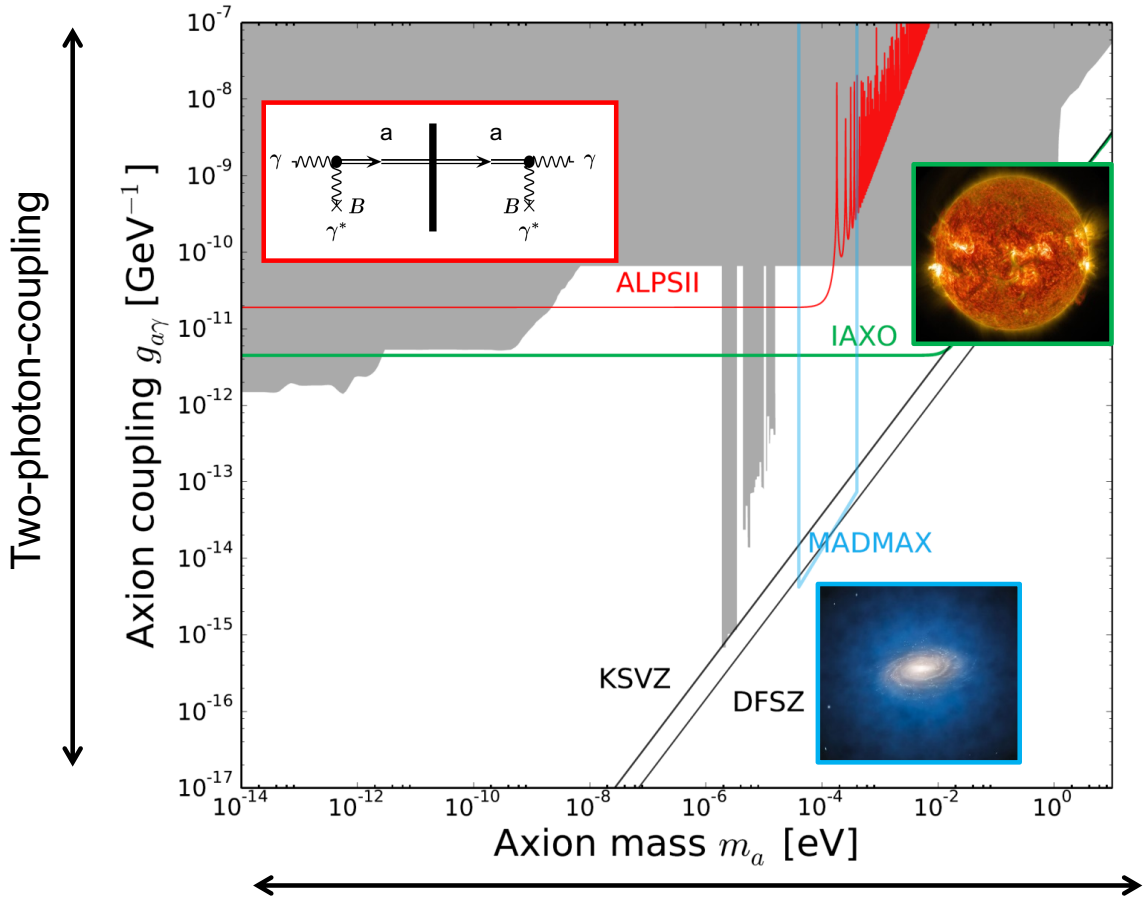
- Axion-like particles:
  TeV transparency, stellar evolution,
  $m_a < 10^{-7}$eV, $g_{a\gamma} = O(10^{-11}\text{GeV}^{-1})$

- QCD axions:
  CP, stellar evolution, (dark matter),
  $m_a = O(10^{-3}\text{eV})$, $g_{a\gamma} = O(10^{-11}\text{GeV}^{-1})$

- QCD axions:
  CP, dark matter,
  $m_a = O(10^{-4}\text{eV})$, $g_{a\gamma} = O(10^{-14}\text{GeV}^{-1})$

Introduction to axions and axion-like particles (ALPs)

Where to look: hot spots in parameter space



Three main regions of interest:

- Axion-like particles:
  TeV transparency, stellar evolution,
  $m_a < 10^{-7}$eV, $g_{a\gamma} = O(10^{-11}\text{GeV}^{-1})$,
  ALPS II.

- QCD axions:
  CP, stellar evolution, (dark matter),
  $m_a = O(10^{-3}\text{eV})$, $g_{a\gamma} = O(10^{-11}\text{GeV}^{-1})$,
  IAXO.

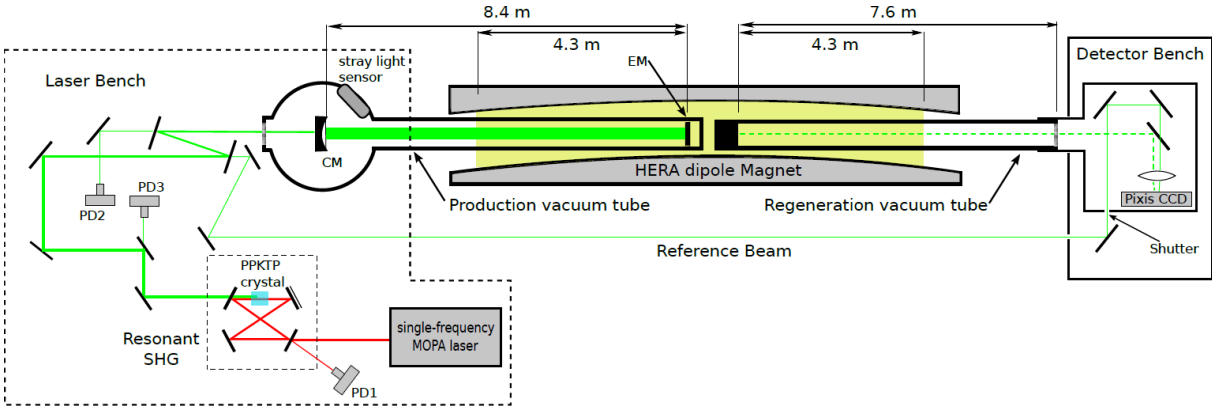
- QCD axions:
  CP, dark matter,
  $m_a = O(10^{-4}\text{eV})$, $g_{a\gamma} = O(10^{-14}\text{GeV}^{-1})$,
  MADMAX.

Any Light Particle Searches @ DESY in Hamburg

From ALPS I to ALPS II

ALPS I

- based on one HERA proton accelerator dipole magnet,
- initiated 2006 by theory, exp. particle physics and administration,
- approved 2007 and concluded 2010,
- most sensitive ALP search experiment in the lab up to 2014.



Basis of success:
combine forces with LIGO community (long optical resonators)
to implement an optical resonator in the magnet bore.

Any Light Particle Searches @ DESY in Hamburg

From ALPS I to ALPS II

ALPS I

- based on one HERA proton accelerator dipole magnet,
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Jinst PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

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REVISED: *June 13, 2013*
ACCEPTED: *July 18, 2013*
PUBLISHED: *September 5, 2013*

TECHNICAL REPORT

Any light particle search II — Technical Design Report

R. Bähre,[a] B. Döbrich,[b] J. Dreyling-Eschweiler,[b] S. Ghazaryan,[b] R. Hodajerdi,[b] D. Horns,[c] F. Januschek,[b] E.-A. Knabbe,[b] A. Lindner,[b,1] D. Notz,[b] A. Ringwald,[b] J.E. von Seggern,[b] R. Stromhagen,[b] D. Trines[b] and B. Willke[a]

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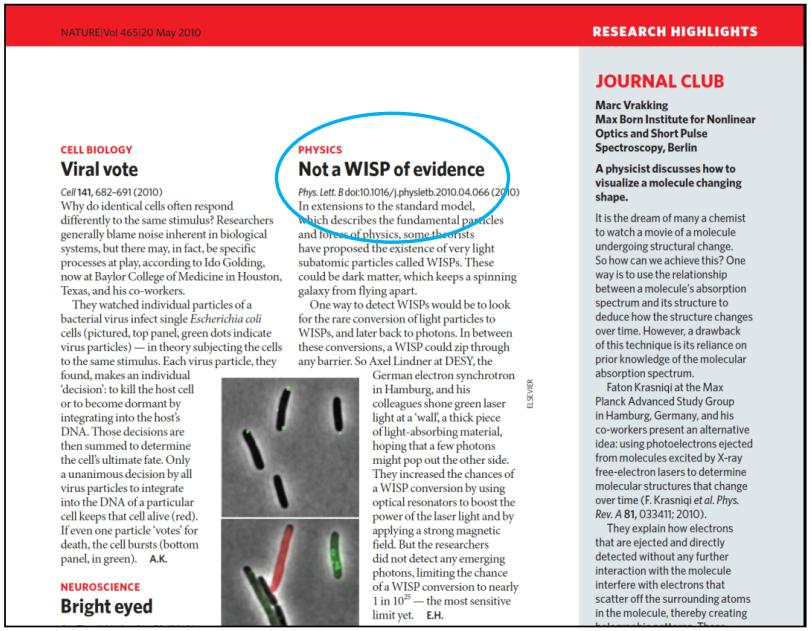
[b]*Deutsches Elektronen-Synchrotron (DESY), Notkestr. 85, 22607 Hamburg, Germany*
[c]*University of Hamburg, Institut für Experimentalphysik, Luruper Chaussee 149, 22761 Hamburg, Germany*

E-mail: axel.lindner@desy.de

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

ALPS II

- proposed 2011,
  TDR evaluated in 2012,
  directorate decided to continue with the preparatory phase,
- construction phase started in 2017.
- Main goal:
  increase sensitivity on $g_{a\gamma}$ by > 10^3
  to probe for axion-like particles motivated by astrophysics.



NATURE|Vol 465|20 May 2010

RESEARCH HIGHLIGHTS

CELL BIOLOGY

Viral vote

Cell **141**, 682–691 (2010)

Why do identical cells often respond differently to the same stimulus? Researchers generally blame noise inherent in biological systems, but there may, in fact, be specific processes at play, according to Ido Golding, now at Baylor College of Medicine in Houston, Texas, and his co-workers.

They watched individual particles of a bacterial virus infect single *Escherichia coli* cells (pictured, top panel, green dots indicate virus particles) — in theory subjecting the cells to the same stimulus. Each virus particle, they found, makes an individual 'decision': to kill the host cell or to become dormant by integrating into the host's DNA. Those decisions are then summed to determine the cell's ultimate fate. Only a unanimous decision by all virus particles to integrate into the DNA of a particular cell keeps that cell alive (red). If even one particle 'votes' for death, the cell bursts (bottom panel, in green). **A.K.**

NEUROSCIENCE

Bright eyed

PHYSICS

Not a WISP of evidence

Phys. Lett. B doi:10.1016/j.physletb.2010.04.066 (2010)

In extensions to the standard model, which describes the fundamental particles and forces of physics, some theorists have proposed the existence of very light subatomic particles called WISPs. These could be dark matter, which keeps a spinning galaxy from flying apart.

One way to detect WISPs would be to look for the rare conversion of light particles to WISPs, and later back to photons. In between these conversions, a WISP could zip through any barrier. So Axel Lindner at DESY, the German electron synchrotron in Hamburg, and his colleagues shone green laser light at a 'wall', a thick piece of light-absorbing material, hoping that a few photons might pop out the other side. They increased the chances of a WISP conversion by using optical resonators to boost the power of the laser light and by applying a strong magnetic field. But the researchers did not detect any emerging photons, limiting the chance of a WISP conversion to nearly 1 in 10^{25} — the most sensitive limit yet. **E.H.**

ELSEVIER

JOURNAL CLUB

Marc Vrakking
Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin

A physicist discusses how to visualize a molecule changing shape.

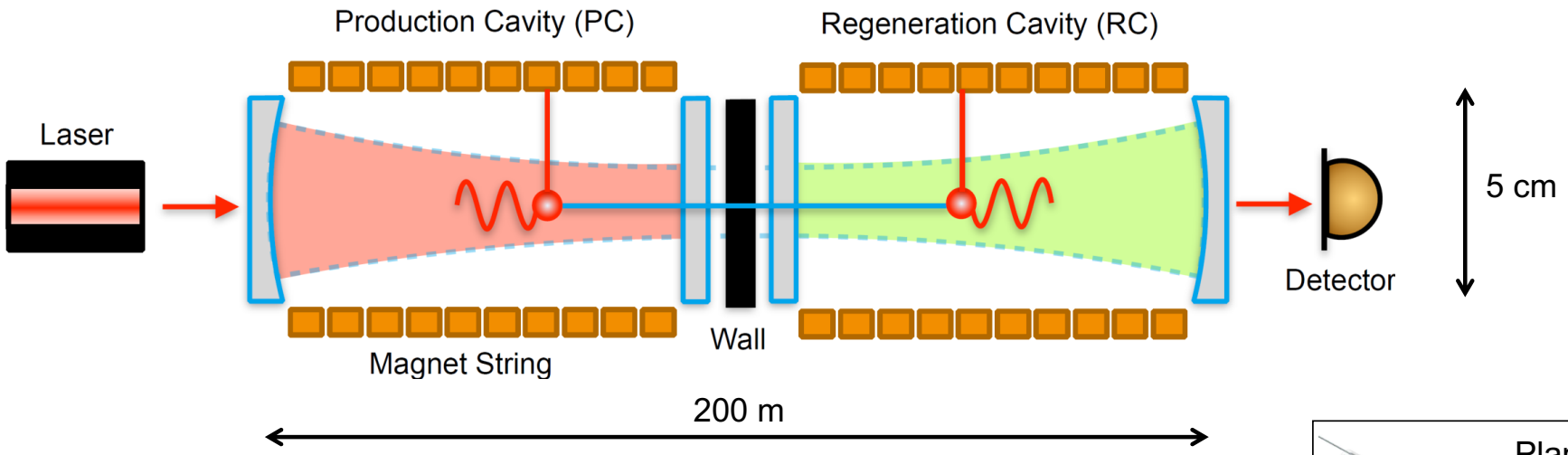
It is the dream of many a chemist to watch a movie of a molecule undergoing structural change. So how can we achieve this? One way is to use the relationship between a molecule's absorption spectrum and its structure to deduce how the structure changes over time. However, a drawback of this technique is its reliance on prior knowledge of the molecular absorption spectrum.

Faton Krasniqi at the Max Planck Advanced Study Group in Hamburg, Germany, and his co-workers present an alternative idea: using photoelectrons ejected from molecules excited by X-ray free-electron lasers to determine molecular structures that change over time (F. Krasniqi *et al. Phys. Rev. A* **81**, 033411; 2010).

They explain how electrons that are ejected and directly detected without any further interaction with the molecule interfere with electrons that scatter off the surrounding atoms in the molecule, thereby creating

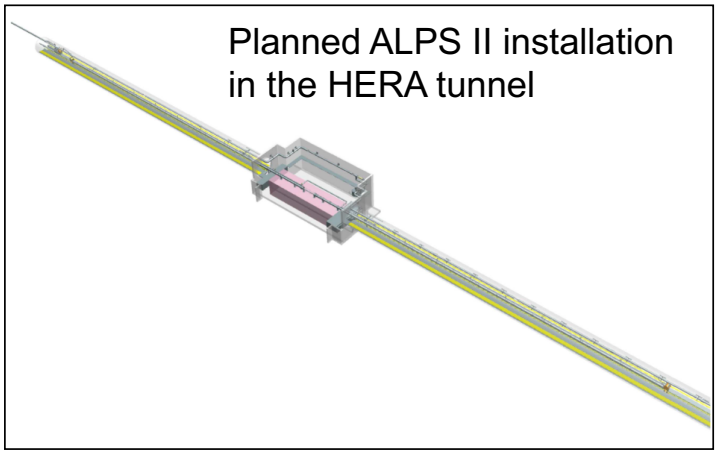
ALPS II @ DESY in Hamburg

Main components



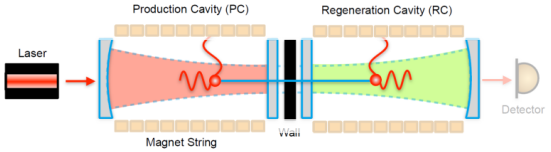
10+10 straightened dipole magnets from the HERA proton accelerator

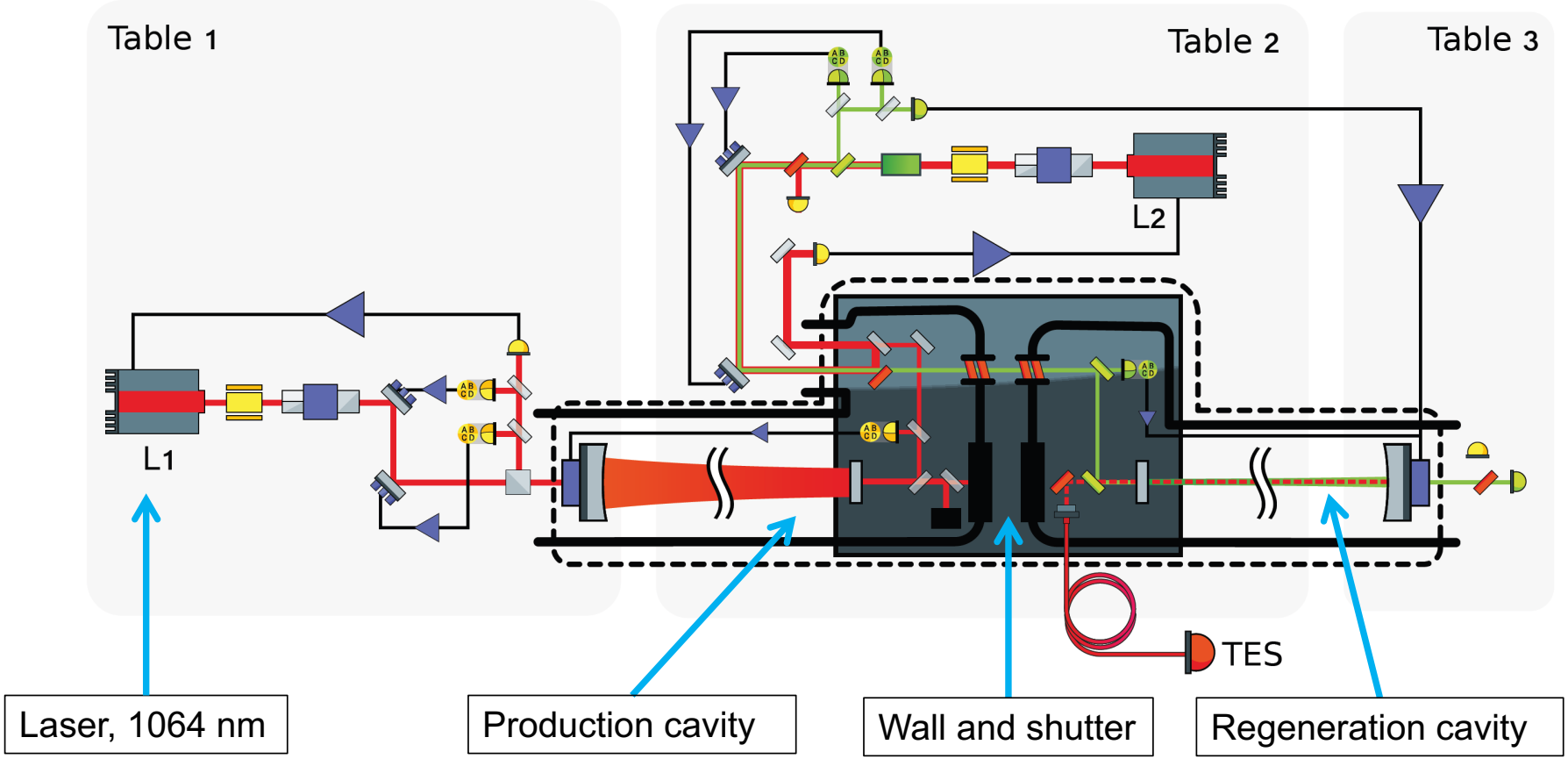
Production Cavity and Regeneration Cavity, mode matched



ALPS II @ DESY in Hamburg

Main components: optics





ALPS II @ DESY in Hamburg

Main components: optics in the 20 m long prototype

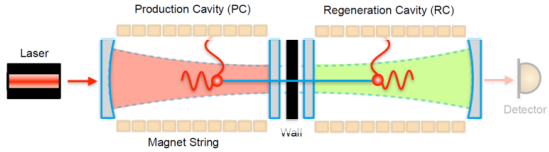
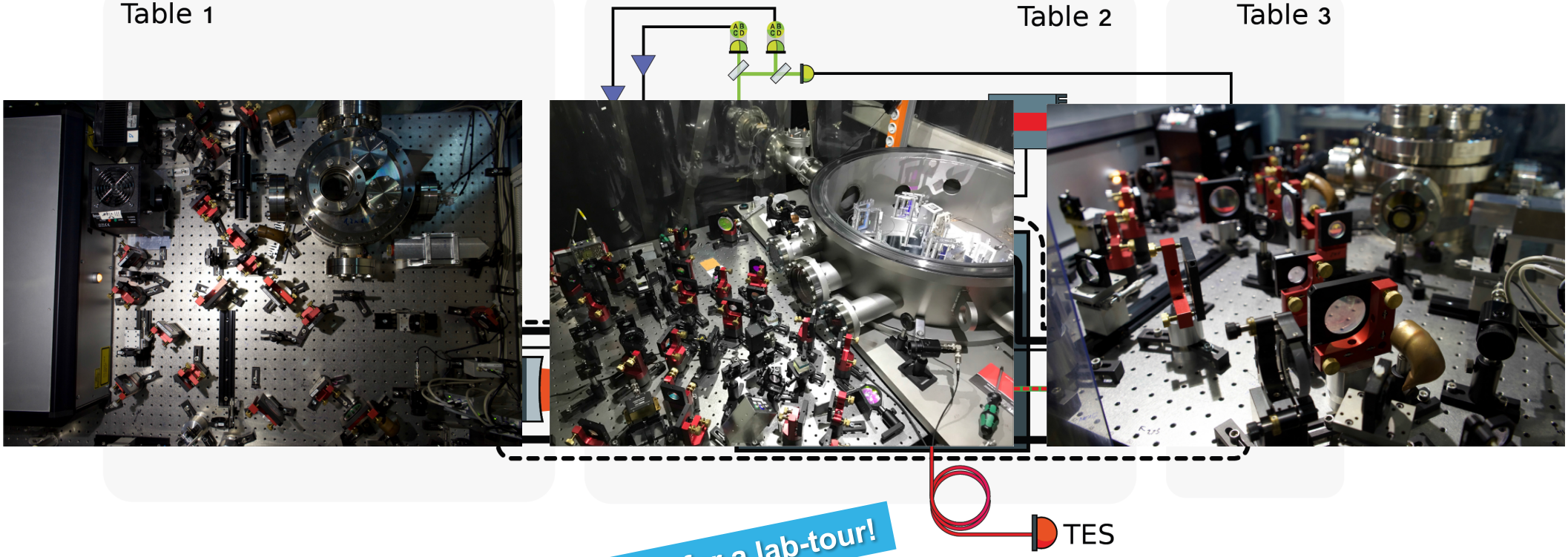


Table 1

Table 2

Table 3

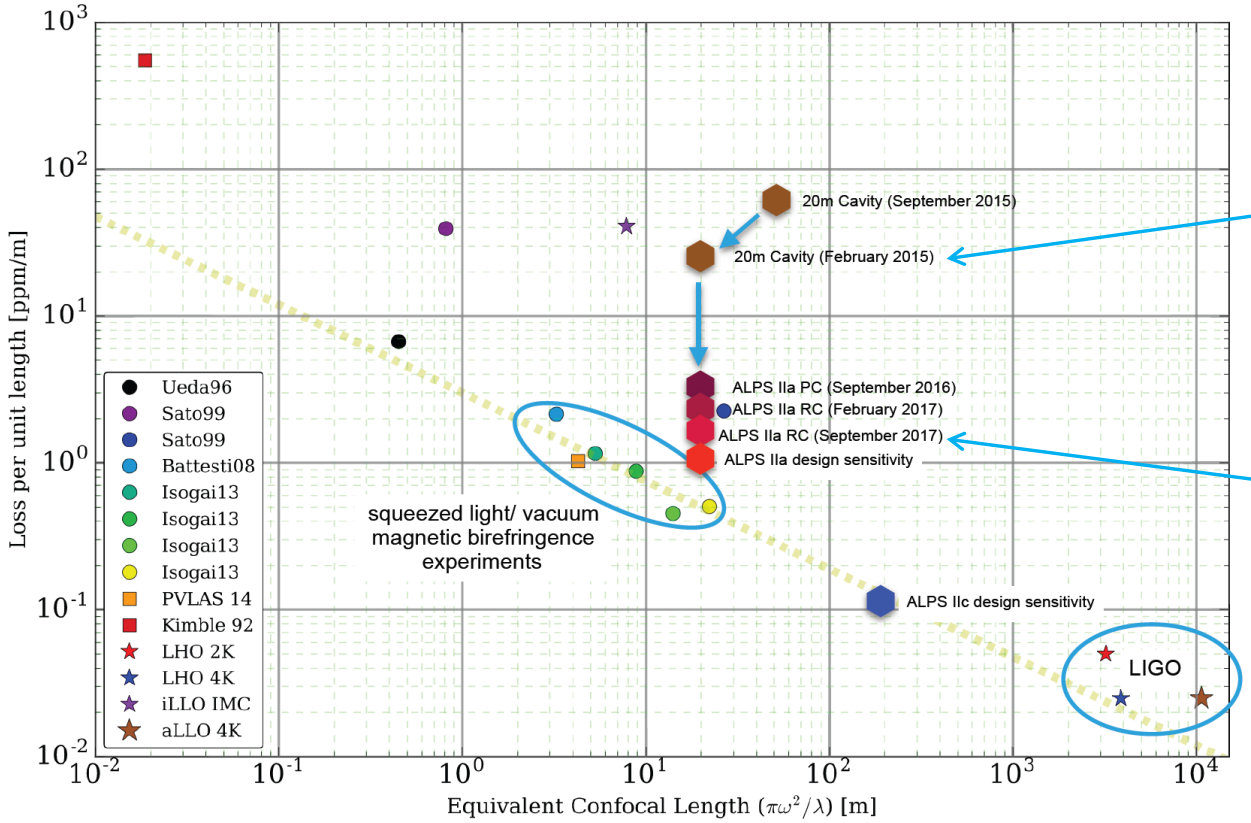


Be invited for a lab-tour!

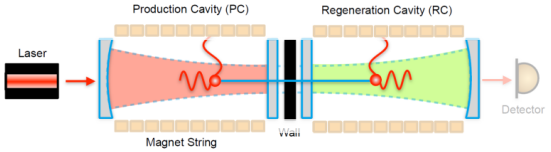
ALPS II @ DESY in Hamburg

Main components: optics achievements in the 20 m long prototype

Long baseline optical resonators: ALPS II optics becomes cutting edge



plot from LIGO T-1400226-v6



Research Article
Vol. 24, No. 25 | 12 Dec 2016 | OPTICS EXPRESS 29237
Optics EXPRESS

Characterization of optical systems for the ALPS II experiment

Aaron D. Spector,[1,*] Jan H. Põld,[2] Robin Bähre,[3,4] Axel Lindner,[2] and Benno Willke [3,4]

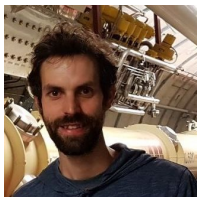
[1]Institut für Experimentalphysik, Universität Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany
[2]Deutsches Elektronen-Synchrotron (DESY), Notkestraße 85, D-22607 Hamburg, Germany
[3]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Callinstraße 38 D-30167 Hannover, Germany
[4]Institute for Gravitational Physics of the Leibniz Universität Hannover, Callinstraße 38, D-30167 Hannover Germany
*aaron.spector@desy.de

Demonstration of the length stability requirements for ALPS II with a high finesse 10 m cavity

Jan H. Põld,[1,*] and Aaron D. Spector[1]

[1]Deutsches Elektronen-Synchrotron (DESY), Notkestraße 85, D-22607 Hamburg, Germany
*jan.pold@desy.de

https://arxiv.org/abs/1710.06634



ALPS II @ DESY in Hamburg

Collaboration

Albert Einstein Institute Hannover

DESY

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

UF UNIVERSITY of FLORIDA

ALPS II main contributions				
Partner	**Magnets**	**Optics**	**Detectors**	**Infrastructure**
DESY*	X	X	X	X
AEI Hannover		X		
U. Florida		X	X	X
U. Mainz			X	

*: theory, experimental particle physics, accelerator division

Significant funding support also by the

HEISING-SIMONS FOUNDATION

ALPS II @ DESY in Hamburg

Results and schedule

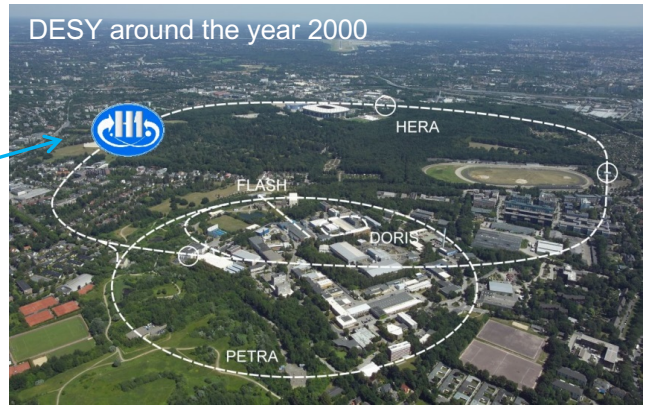
Results:

- Axions and ALPs:
  none (no data run yet …)
- Publications:
  5 on optics and detector developments;
  several conference contributions.
- People (since 2012):
  6 Ph.D. theses completed,
  about 8 to come,
  4 postdocs left for a next career step.

Schedule:

- Start data taking in the HERA tunnel in early 2020.

HERA hall North
(former H1 experiment at HERA)



On-site experiments

A timeline

2012:
ALPS II
R&D

2017:
ALPS II
construction

2020:
ALPS II
data run

Future options:

2021:
Prototypes MADMAX, IAXO ?

2022: LUXE ?

Future option I: MAgnetized Disc and Mirror Axion eXperiment

Direct dark matter search with MADMAX

Collaboration:

- 8 Institutes from 3 countries.
- Formal collaboration founding 20 October 2017 at DESY.

Max-Planck-Institut für Physik

DESY

UHH

Max-Planck-Institut für Radioastronomie

Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers

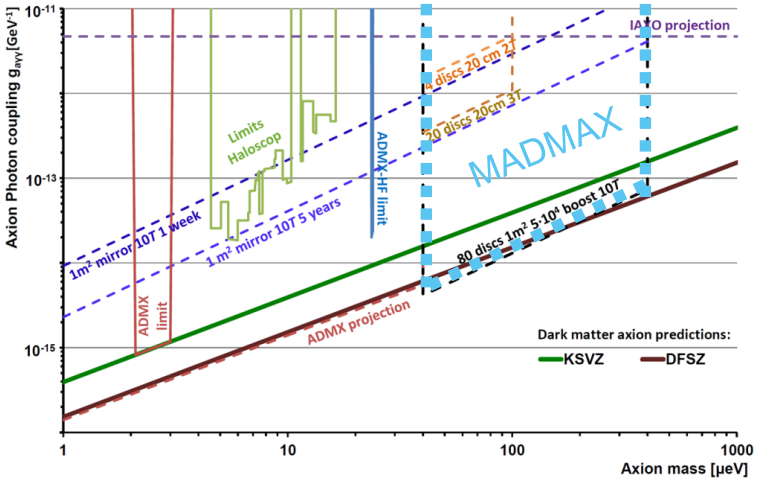
RWTH AACHEN UNIVERSITY

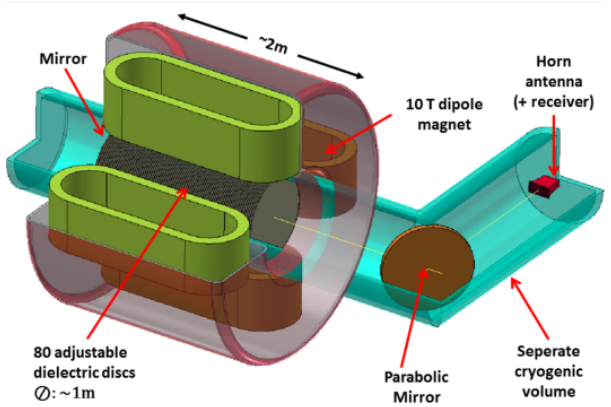
Universidad Zaragoza

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Experiment:

- Motivation:
  look for well motivated axion dark matter (for example "SMASH") in a mass region not accessible by present techniques.
- Approach:
  install a tunable "booster" of 80 dielectric disks inside a 2 m long dipole magnet providing
  $B^2 \cdot A = 100\ T^2m^2$.
- Timeline:
  prototype ready in 2021.
- Location:
  next to ALPS II in HERA North, funding proposal for infrastructure approved by Helmholtz.





Future option II: International AXion Observatory

Searching for solar axions with IAXO

Collaboration:

- 17 Institutes from 8 countries.
- Formal collaboration founding 03 July 2017 at DESY.
- DESY has offered to host IAXO.

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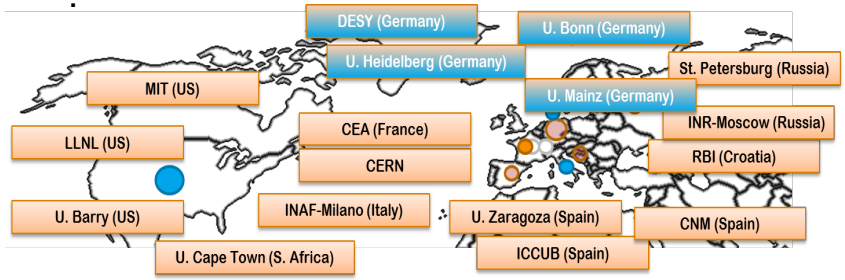
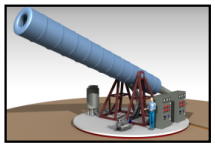


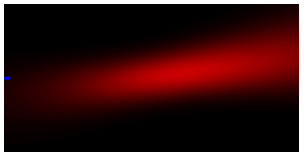
Experiment:

- Motivation:
  explore a well motivated axion parameter region (for example stellar evolutions) not accessible by other techniques.
- Approach:
  use experience gained at CAST (CERN) to optimize solar axion searches with dedicated magnets, X-ray optics and detectors.
- Timeline:
  prototype ready in 2021.
- Location:
  several options at DESY in Hamburg.



Free bore [m]	0.6
Magnetic length [m]	10
Field in bore [T]	2.5
Stored energy [MJ]	27
Peak field [T]	4.1

Future option III: Laser Und XFEL Experiment



Probing nonperturbative QED with LUXE

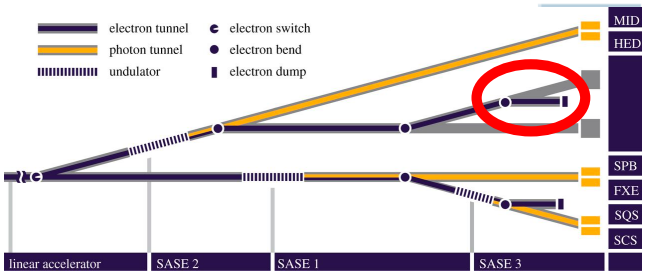
Physics:

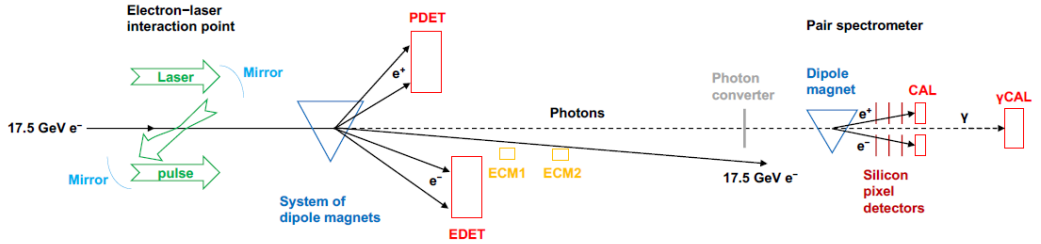
- Probe the strong field regime of QED around $E_{crit} = \frac{m_e^2 c^3}{e\hbar} \approx 1.3\times10^{18}$ V/m .
- Might be relevant also for astrophysics (neutron stars) and atomic/molecular physics.
- Goal: extend the parameter range of E144 (SLAC 1999) by an order of magnitude.

Technique:

- Collide the European XFEL electron beam (17.5 GeV) with a laser providing 10^{21} W/cm^2 at 500 nm.
- Measure the rate of $e^-+n\omega \rightarrow e^- e^+e^-$ and compare its asymptotic value to QED predictions.

Possible layout:





Status:

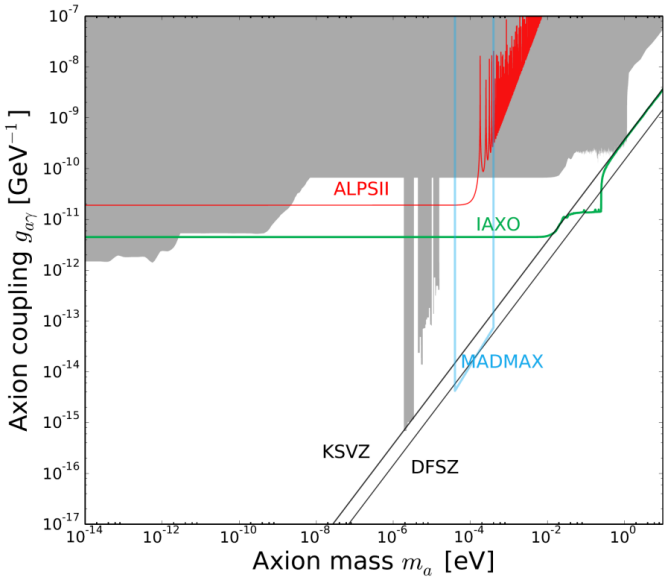
- First discussions on feasibility ongoing:
- Supported by the DESY Strategy Fund.

Summary

Experimental particle physics on-site

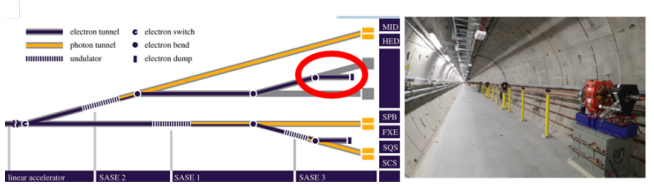
Axion / axion-like particle experiments:

- DESY expertise and infrastructure in collaboration with strong partners provide excellent opportunities for a break-through in hidden sector searches.
- ALPS II is under construction, DESY contributes to the preparation of MADMAX and IAXO. All three will be world-leading.
- New collaboration among different communities have formed, for example ALPS II: particle physics and gravitational waves



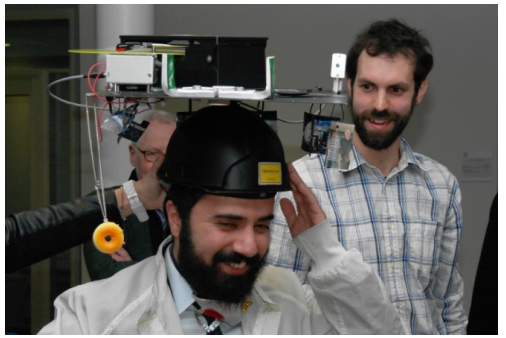
Probing nonperturbative QED with LUXE:

- Opportunities for particle physics with the unique electron beam of the European XFEL are being explored.



ALPS II and future particle physics on-site experiments at DESY in Hamburg

- (re-) use DESY's unique infrastructure and capabilities,
- perfectly complement DESY's engagement in remote experiments,
- offer a unique environment for the development of young people.



R. Hodajerdi, ALPS II

Supplements

Axions

CP conservation of QCD and the neutron’s EDM

Text

Axions

Indications from astrophysics

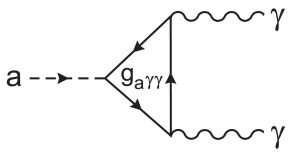
Text

Introduction to axions and axion-like particles (ALPs)

How to look: exploiting photon couplings

Decay to photons

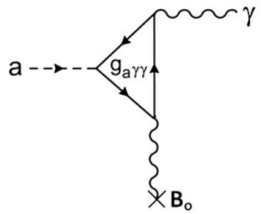
- Not observable in the parameter region addressed here.



Axion lifetime: $\tau(m=1eV) = 10^{16}$ yr

Conversion in a magnetic field

- Primakoff-like effect (Sikivie '83)



B=10T, l=10m $P(a \rightarrow \gamma) \approx 10^{-18}$

Axions and ALPs

Three different approaches

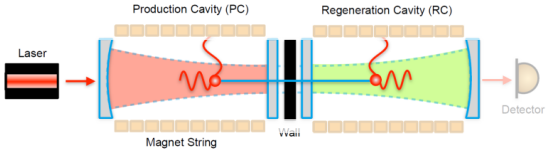
Pros and Cons of LSW, Helio, Halo

Axions

LSW in the lab

Summary of proposals and three independent inventions.

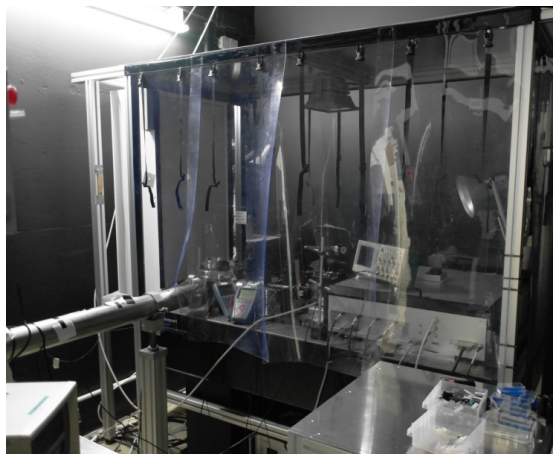
ALPS II @ DESY in Hamburg



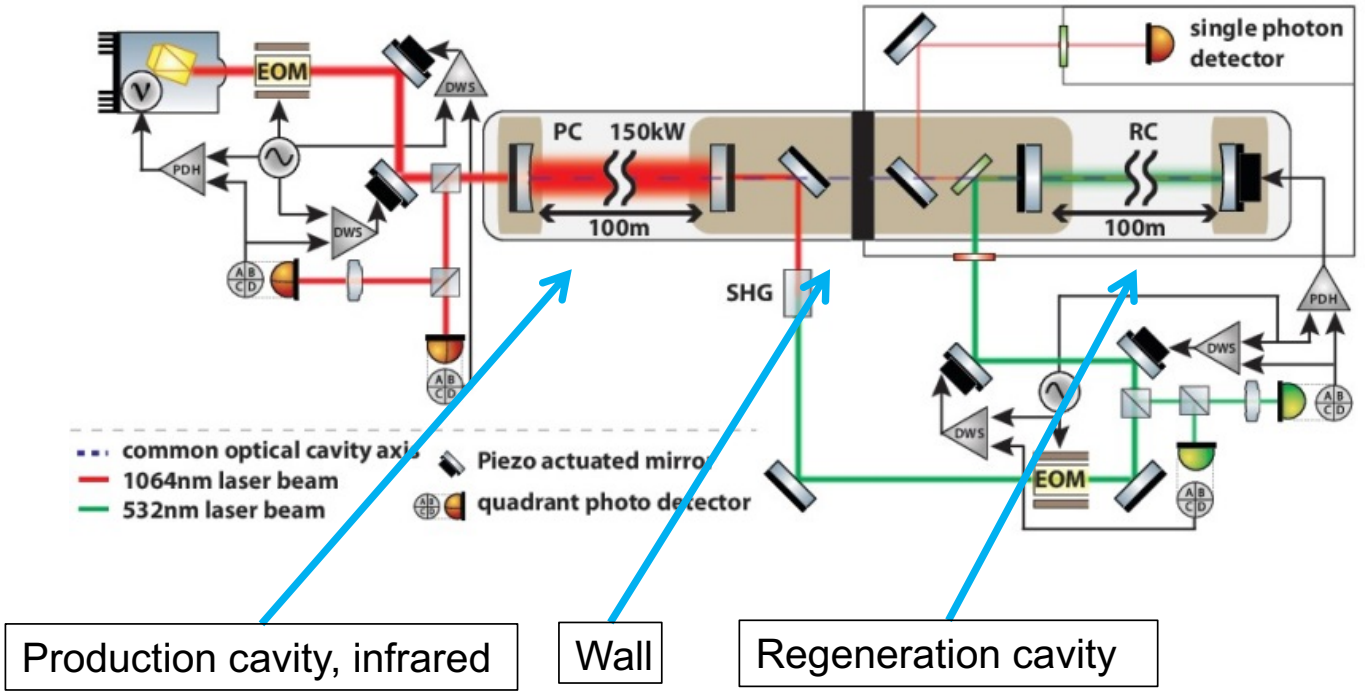
Main components: optics

Laser:

- developed for LIGO,
- based on 2 W NPRO by Innolight/Mephisto (Nd:YAG, neodymium-doped yttrium aluminium garnet),
- 1064 nm, 35 W, M^2<1.1

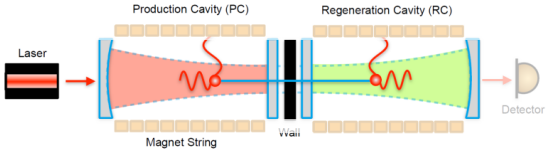


Cavities

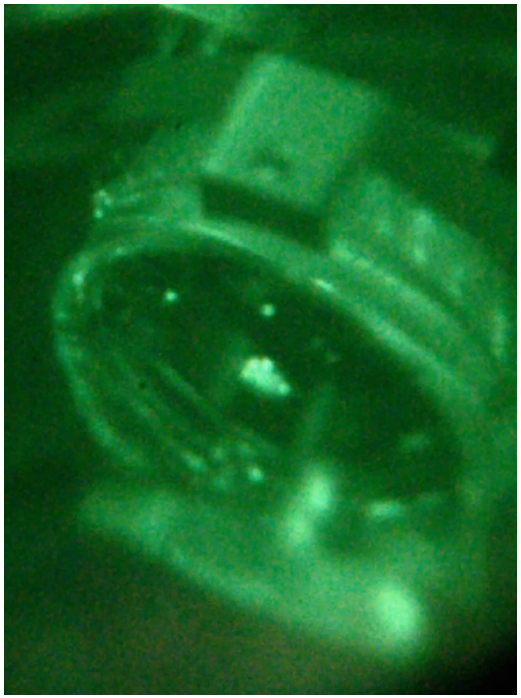


ALPS II @ DESY in Hamburg

Main components: optics achievements in the 20 m long prototype



Cavities in the 20 m ALPS IIa laboratory



	Requirement	Status
PC circulating power	150 kW	50 kW
RC power buildup factor	40,000	23,000
CBB mirror alignment	< 5 µrad	< 1 µrad
Spatial overlap	> 95%	work ongoing
RC length stabilization	< 0.5 pm	< 0.3 pm

Probably caused by micro-roughness of the mirror substrates.

MADMAX

Comparison to other experiments

LUXE

Alternative approaches

Comparison E144

Comparison FACET, ELI