# Searching for WISPs in the lab
# ALPS II @ DESY

**7th SYMPOSIUM ON LARGE TPCs**
**FOR LOW-ENERGY RARE EVENT DETECTION**

16 December 2014

Axel Lindner, DESY

HELMHOLTZ
ASSOCIATION

DESY

# A brief primer on

- W
- I
- S
- P
- S

# A brief primer on

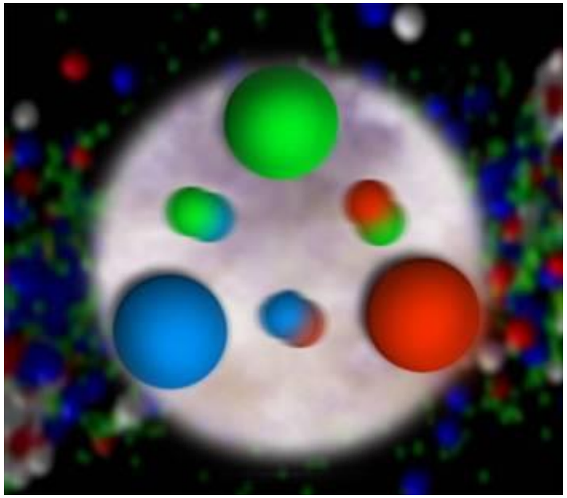
- **W**eakly
- **I**nteracting
- **S**lim
- **P**article
- **S**earches

# Outline

- **W**hy should one look for WISPs
- **I**ndications for WISPs
- **S**earches
- **P**hotons-through-a-wall
- **S**ummary

# There might be physics beyond the SM

> Why does the static electromagnetic dipole moment of the neutron vanish?



Why do the wave functions of the three quarks *exactly* cancel out any observable static charge distribution in the neutron?

http://www.lbl.gov/Science-Articles/Archive/sabl/2006/Oct/3.html

> This is related to a fundamental property of QCD:

QCD allows for CP violation, if the quarks have non-zero masses.
Why does QCD nevertheless conserve CP?

# There might be physics beyond the SM

- CP-conservation in QCD is a fine tuning issue:

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  F. Wilczek at “Vistas in Axion Physics”, Seattle, 26 April 2012
  (see http://www.int.washington.edu/talks/WorkShops/int_12_50W/People/Wilczek_F/Wilczek.pdf)

  *The overall phase of the quark mass matrix is physically meaningful.*
  *In the minimal standard model, **this phase is a free parameter**, theoretically.*
  *Experimentally it is very small.*
  *This is the most striking unnaturality of the standard model, aside from the cosmological term. It does not seem susceptible of anthropic “explanation”.*

- The observable CP-violation in QCD is given by $\theta + \arg(\det \mathcal{M})$



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- The observable CP-violation in QCD is given by $\theta + \arg(\det \mathcal{M})$

- Experimentally, $|\theta + \arg(\det \mathcal{M})| < 10^{-9}$.

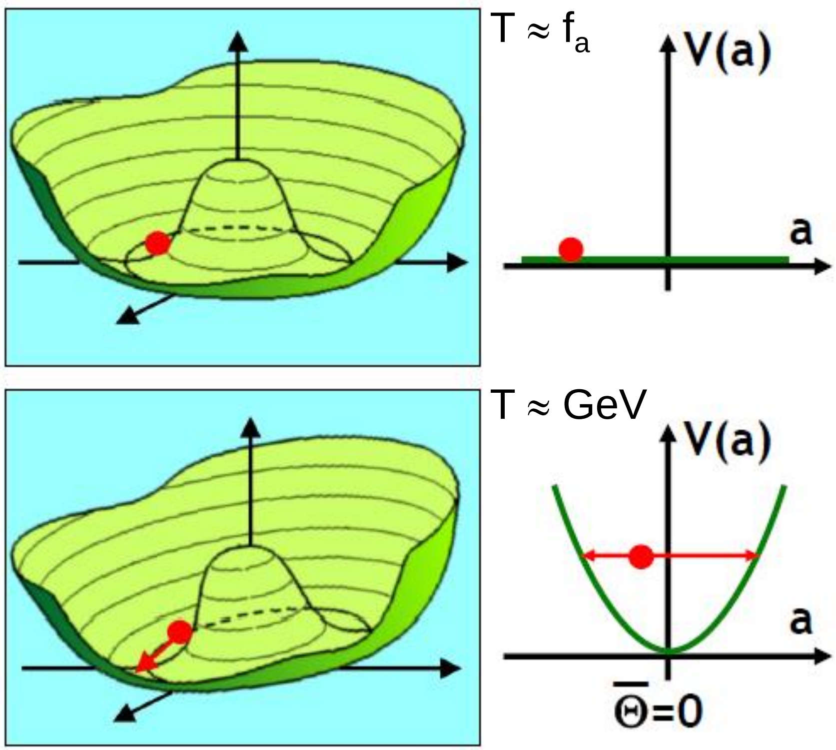
  **A "fine-tuning" problem!**

# The first WISP: introducing the axion

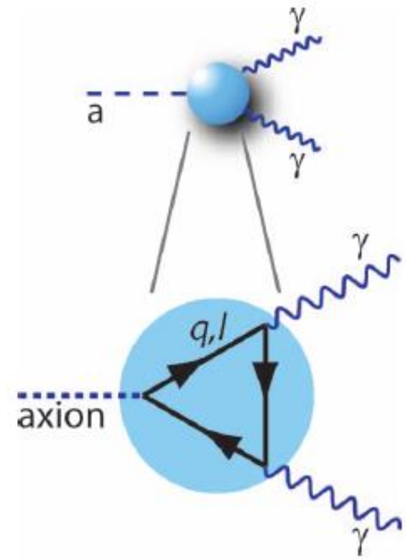
- CP-conservation in QCD:

A dynamic explanation predicts the axion, which couples very weakly to two photons.

Peccei-Quinn 1977




Wilczek and Weinberg 1978




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

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

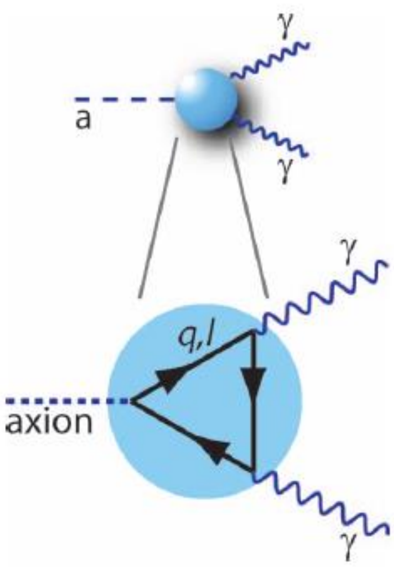
# Properties of the axion

> The QCD axion: light, neutral pseudoscalar boson.

> The QCD axion: the light cousin of the $\pi^0$.

- Mass and the symmetry breaking scale $f_a$ are related:
  $m_a = 0.6\text{eV} \cdot (10^7\text{GeV} / f_a)$

- The coupling strength to photons is
  $g_{a\gamma\gamma} = \alpha \cdot g_\gamma / (\pi \cdot f_a)$,
  where $g_\gamma$ is model dependent and O(1).
  Note: $g_{a\gamma\gamma} = \alpha \cdot g_\gamma / (\pi \cdot 6 \cdot 10^6\text{GeV}) \cdot m_a$

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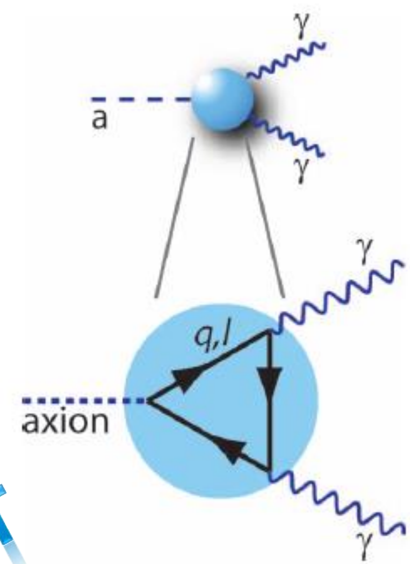
    Note: $g_{a\gamma\gamma} = \alpha \cdot g_\gamma / (\pi \cdot 6 \cdot 10^6\text{GeV}) \cdot m_a$
  - The axion abundance in the universe is
    $\Omega_a / \Omega_c \sim (f_a / 10^{12}\text{GeV})^{7/6}$.

    $f_a < 10^{12}\text{GeV}$
    $m_a > \mu\text{eV}$

NON-THERMAL ORIGIN
FROM VACUUM RE-ALIGNMENT

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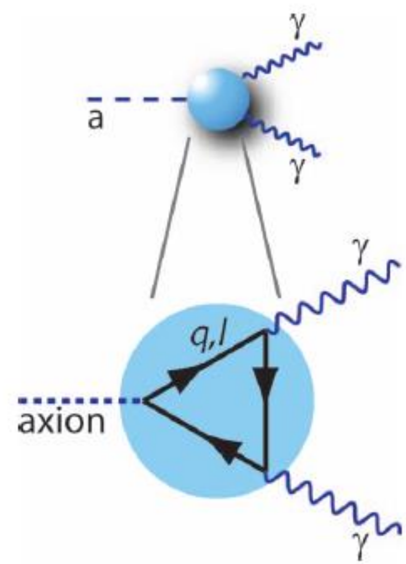
VERY LIGHTWEIGHT COLD DARK MATTER!

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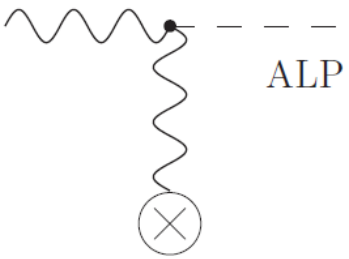
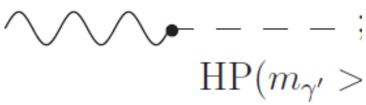
# More general: WISPy particles

Weakly Interacting Slim Particles (WISPs):

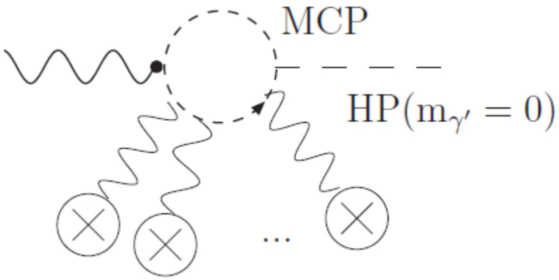
- Axions and
  **axion-like particles**
  **ALP**s, pseudoscalar or scalar bosons,
  m and g are not related by an f.




- Hidden photons (neutral vector bosons)




- Mini-charged particles




- Chameleons (self-shielding scalars), massive gravity scalars

# Such WISPs are expected by theory

- Axions, ALPs and other WISPs occur naturally in string theory inspired extensions of the standard model as components of a “hidden sector”.

JHEP
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Received: July 13, 2012
Accepted: September 17, 2012
Published: October 22, 2012

**The type IIB string axiverse and its low-energy phenomenology**

Michele Cicoli,[a,b] Mark D. Goodsell[c] and Andreas Ringwald[d]

DOI: 10.1007/JHEP10(2012)146
http://www.arxiv.org/abs/1206.0819v1

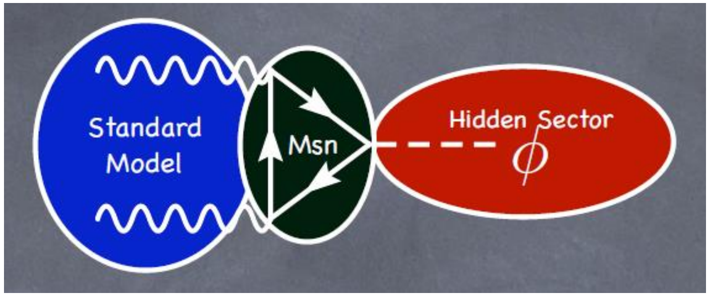
JHEP
Published for SISSA by Springer
Received: April 10, 2014
Accepted: May 19, 2014
Published: June 6, 2014

**The quest for an intermediate-scale accidental axion and further ALPs**

A.G. Dias,[a] A.C.B. Machado,[b] C.C. Nishi,[a] A. Ringwald[c] and P. Vaudrevange[d]

DOI: 10.1007/JHEP06(2014)037
http://arxiv.org/abs/arXiv:1403.5760

- Their weak interaction might be related to very heavy messenger particles.
  Thus WISPs may open up a window to particle physics at highest energies.



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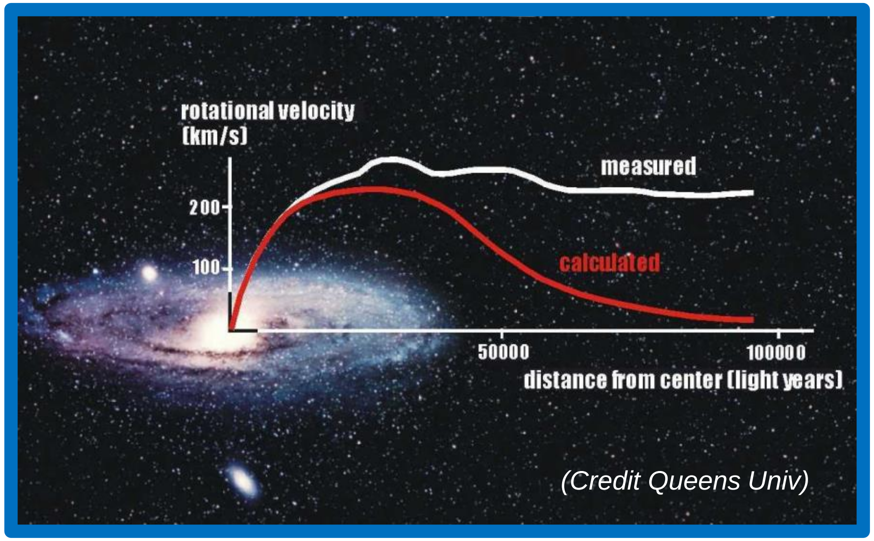
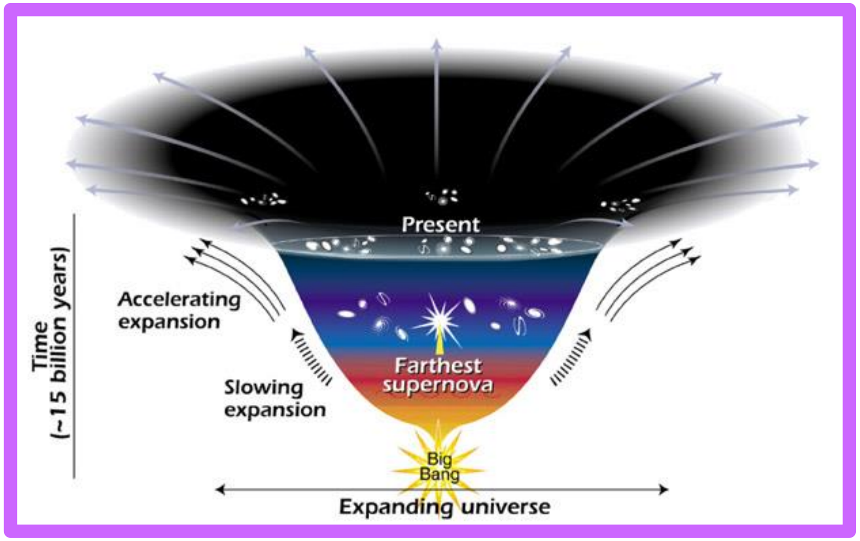
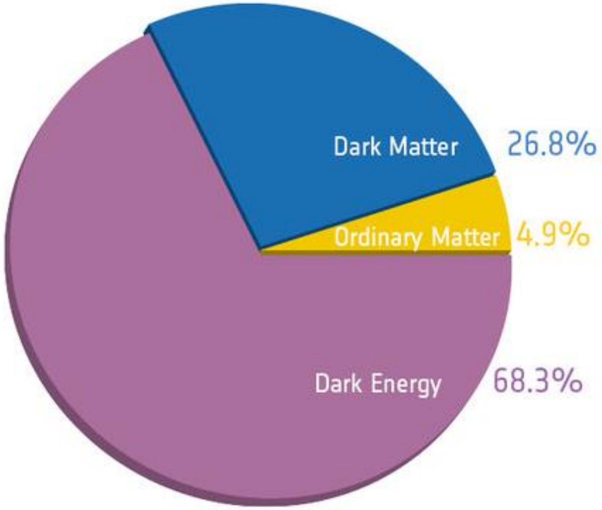
# There is physics beyond the SM

- Dark matter and dark energy:




http://science.nasa.gov/astrophysics/focus-areas/what-is-dark-energy/

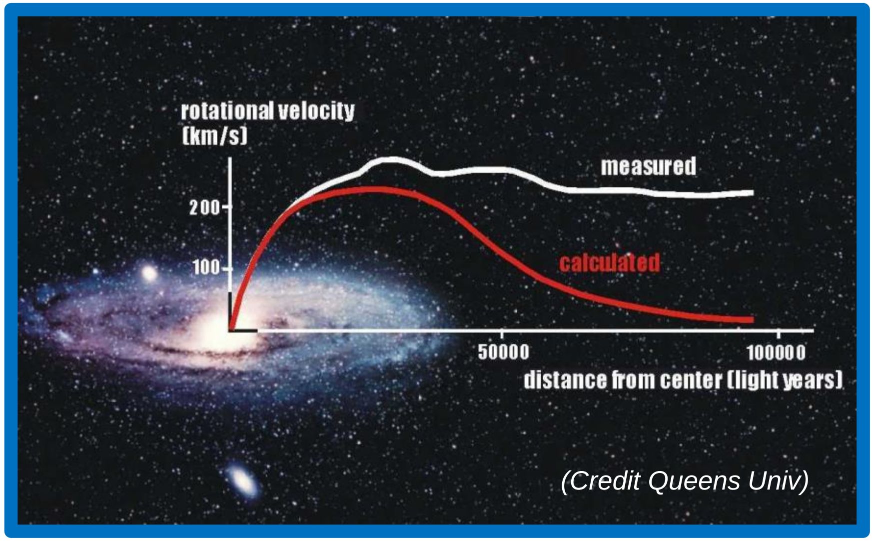


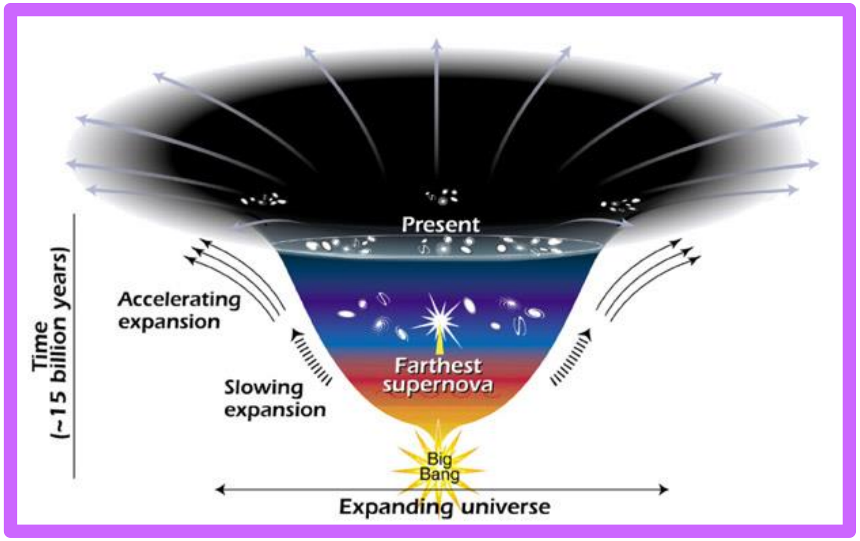

http://www.esa.int/For_Media/Photos/Highlights/Planck

Even if one neglects dark energy:
85% of the matter is of unknown constituents.

# There is physics beyond the SM

- Dark matter and dark energy candidate constituents:

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- Very weak interaction with SM matter
- Very weak interaction among themselves
- Stable on cosmological times
- Non-relativistic

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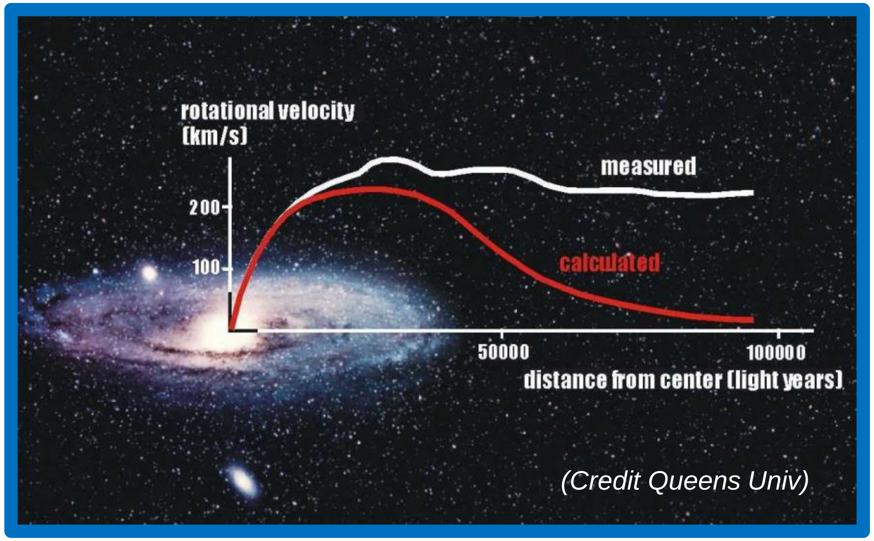


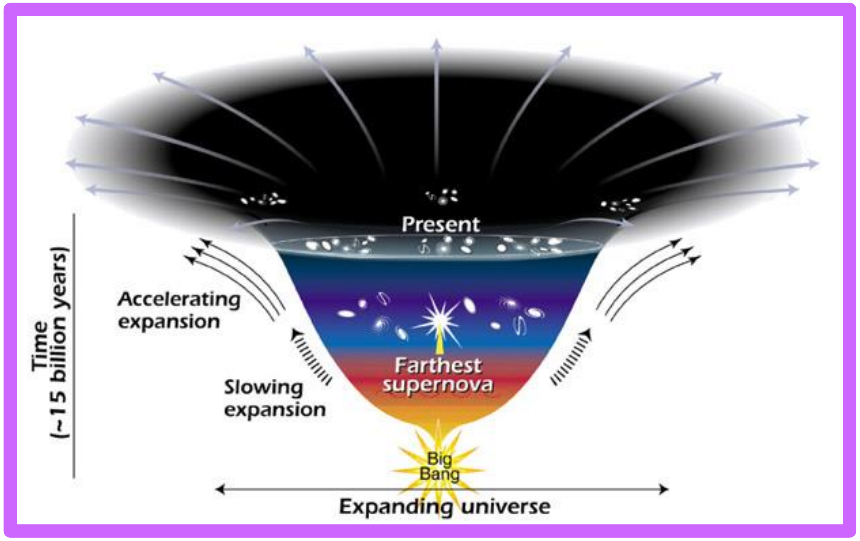


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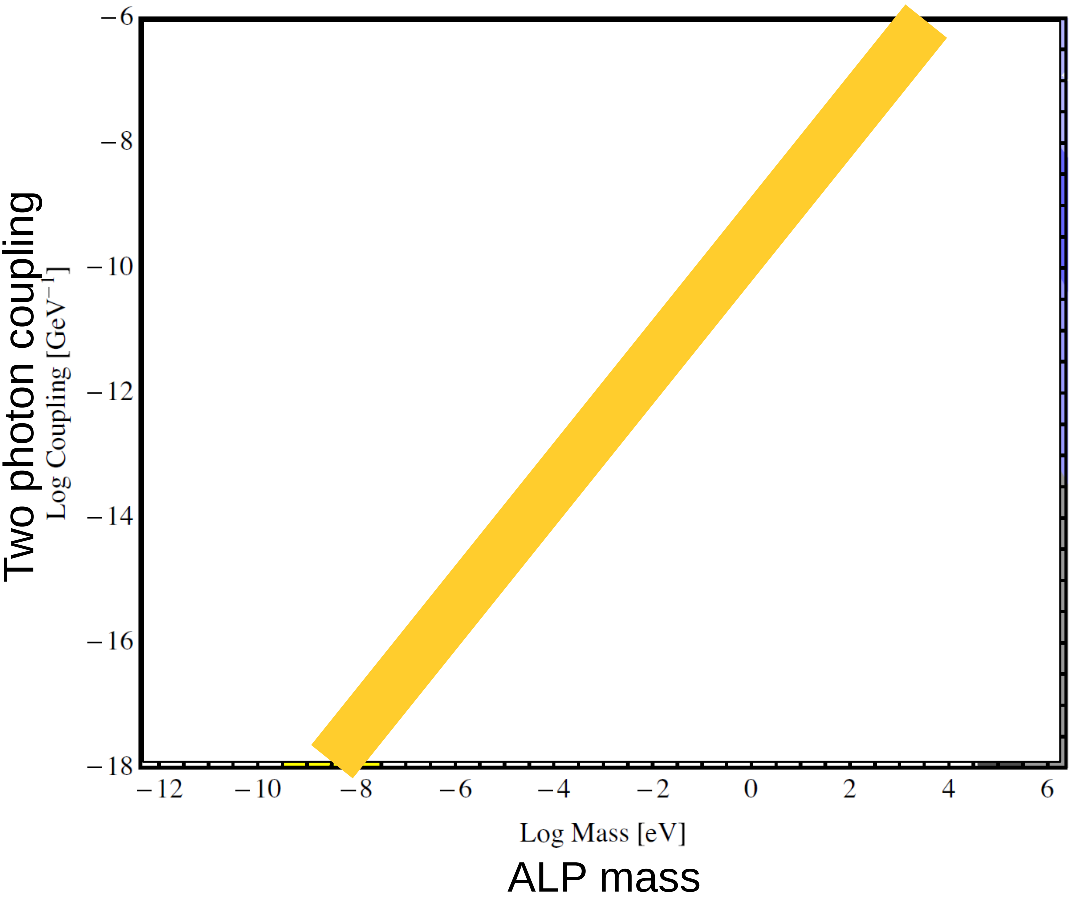
NO HINT ON MASS OF DM CONSTITUENTS!

- Extremely lightweight scalar particle

# Outline

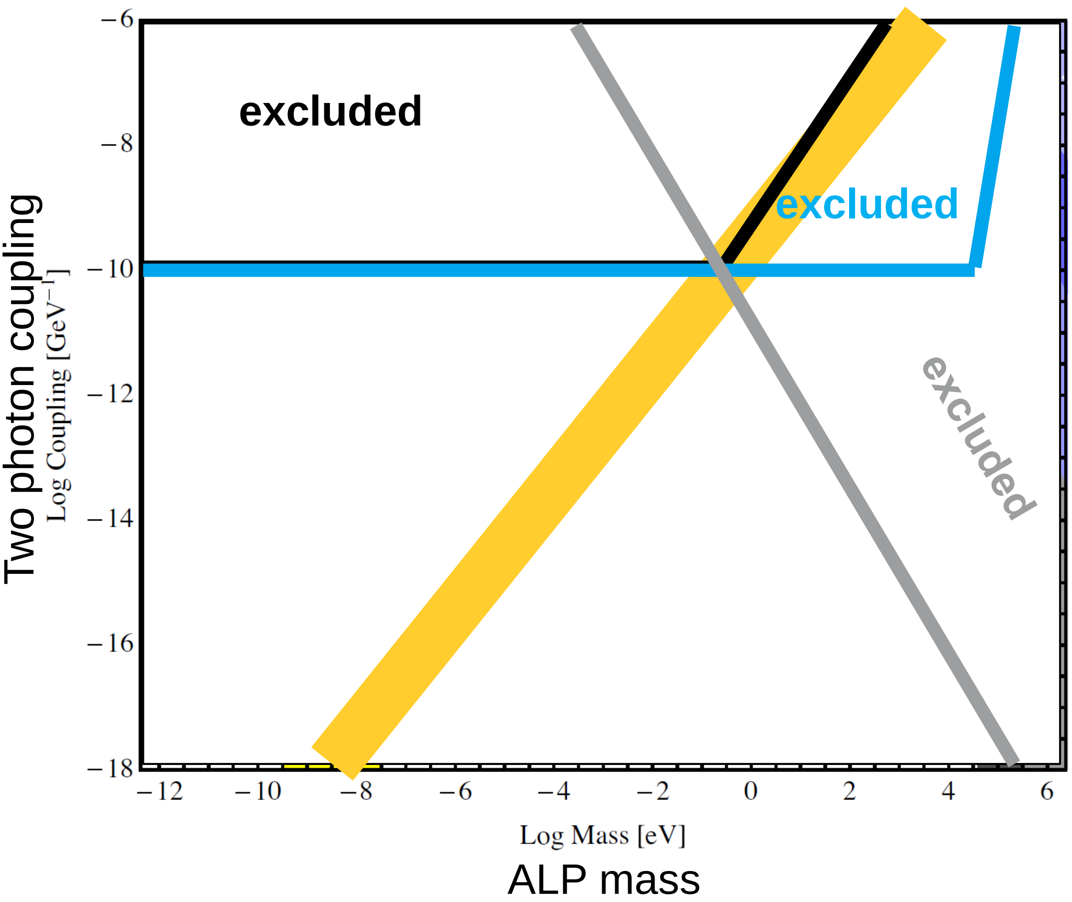
- Why should one look for WISPs
- Indications for WISPs
- Searches
- Photons-through-a-wall
- Summary

# The big picture: ALPs




QCD axion range

# The big picture: ALPs exclusions




QCD axion range
Excluded by WISP experiments
Excluded by astronomy (ass. ALP DM)
Excluded by astrophysics / cosmology

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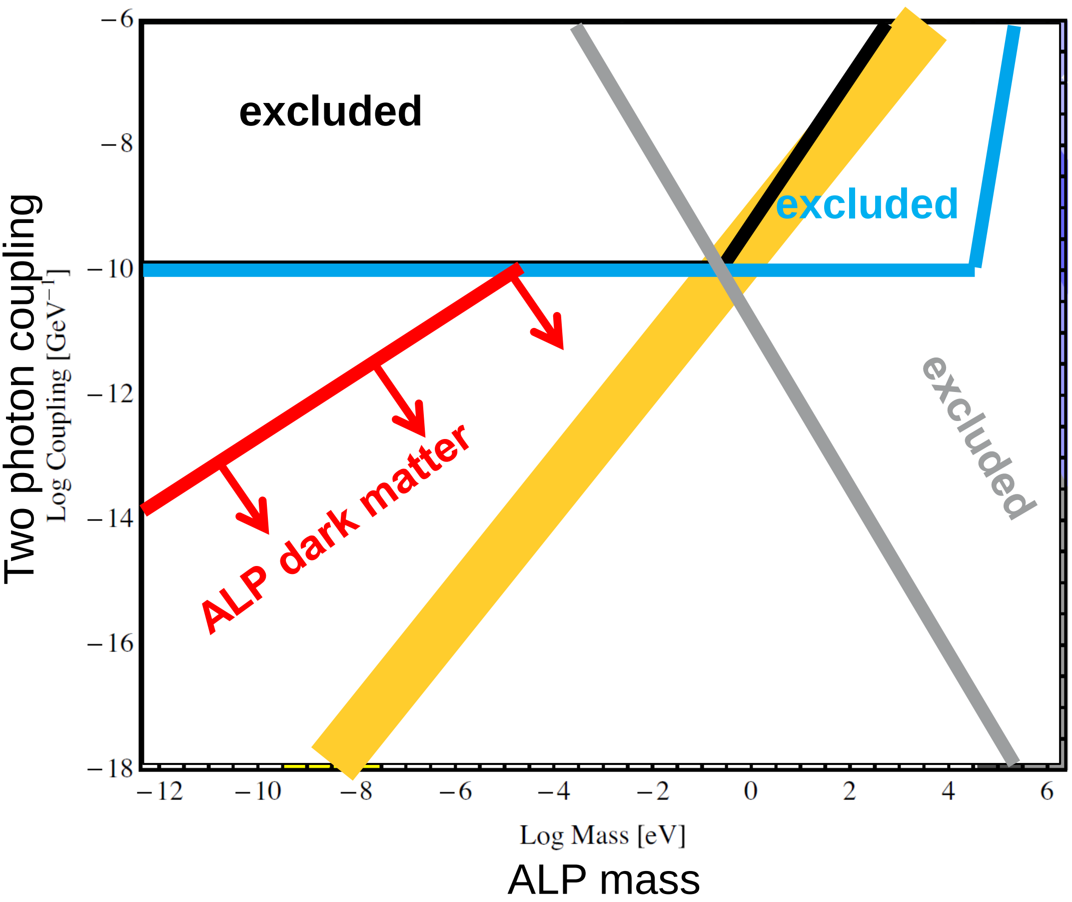


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**Axions or ALPs being cold dark matter**

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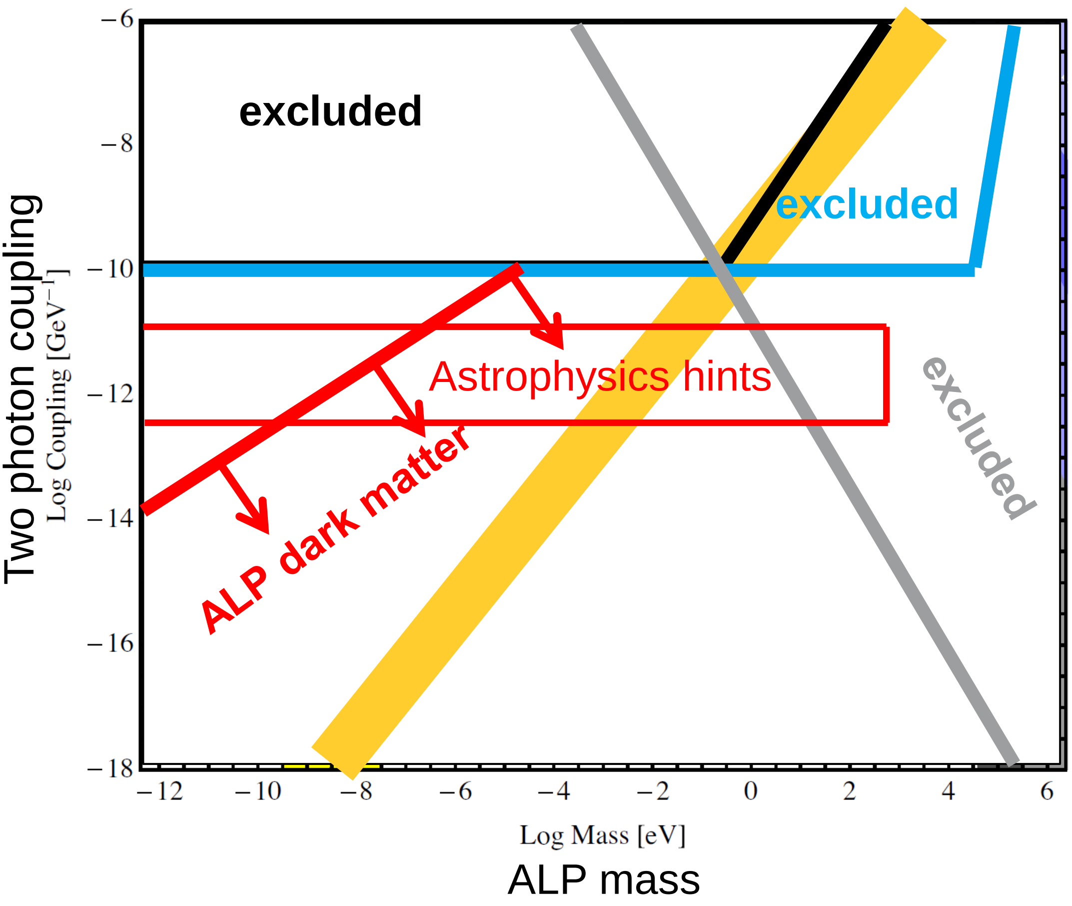


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WISP hints from astrophysics

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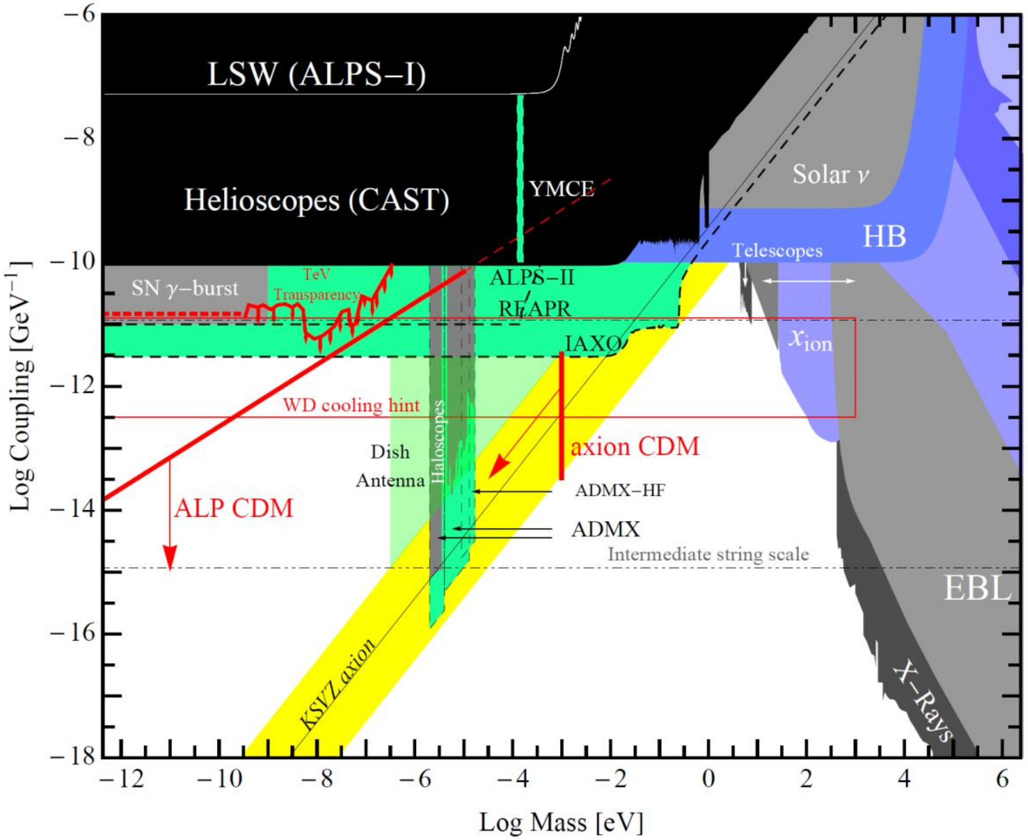



Dark Universe 1 (2012) 116–135

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journal homepage: www.elsevier.com/locate/agee

ELSEVIER

Exploring the role of axions and other WISPs in the dark universe

Andreas Ringwald

Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, D-22607 Hamburg, Germany


DOI: 10.1016/j.dark.2012.10.008

e-Print: **arXiv:1210.5081 [hep-ph]**


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

**Sensitivity of next generation WISP exp.**

Particular interesting:

- ALP-photon couplings around $10^{-11}$GeV$^{-1}$, masses below 1 meV.
  **This can be probed by the next generation of experiments.**



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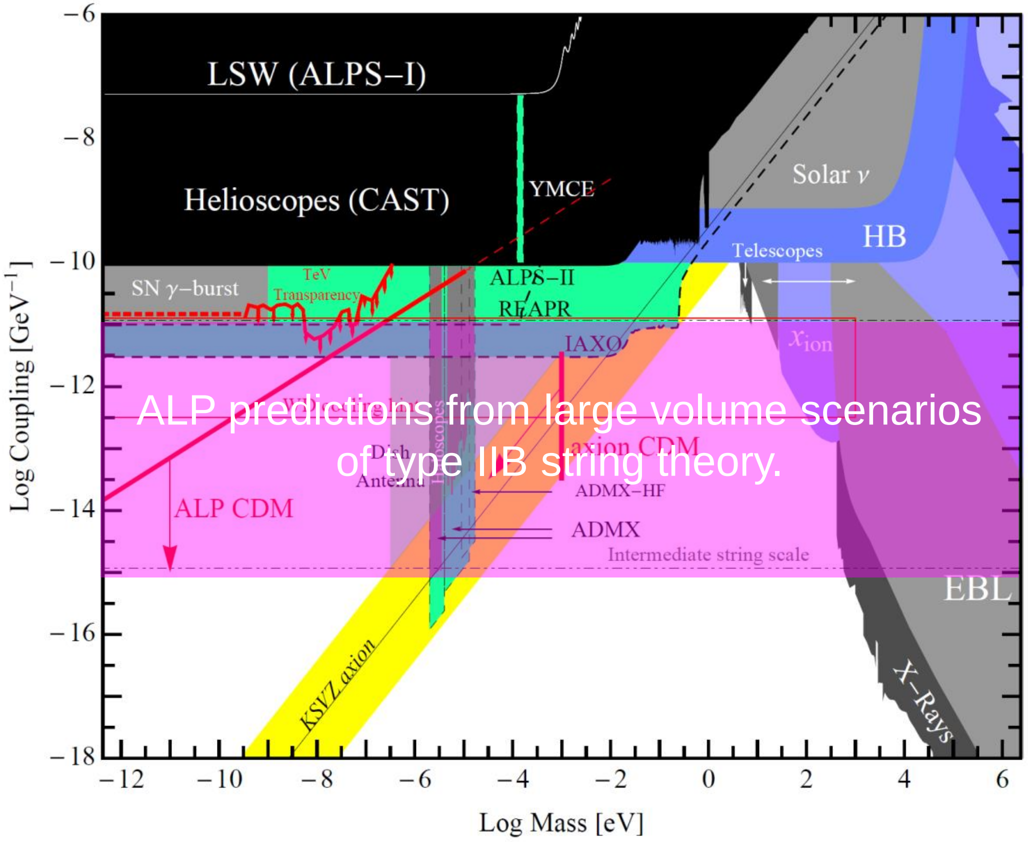
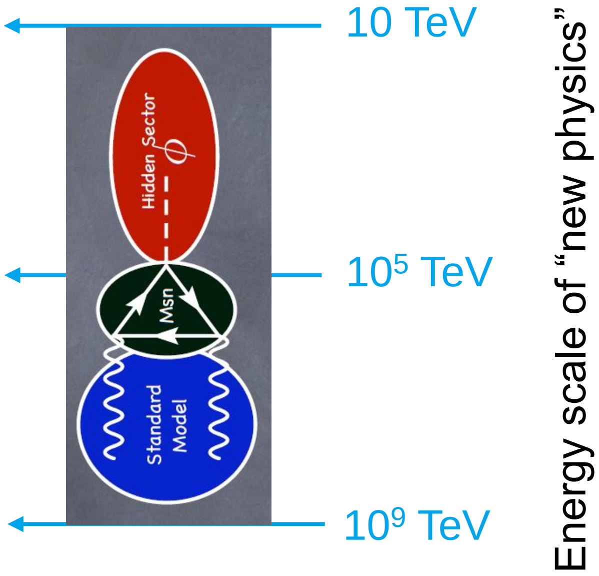
# The big picture: ALPs



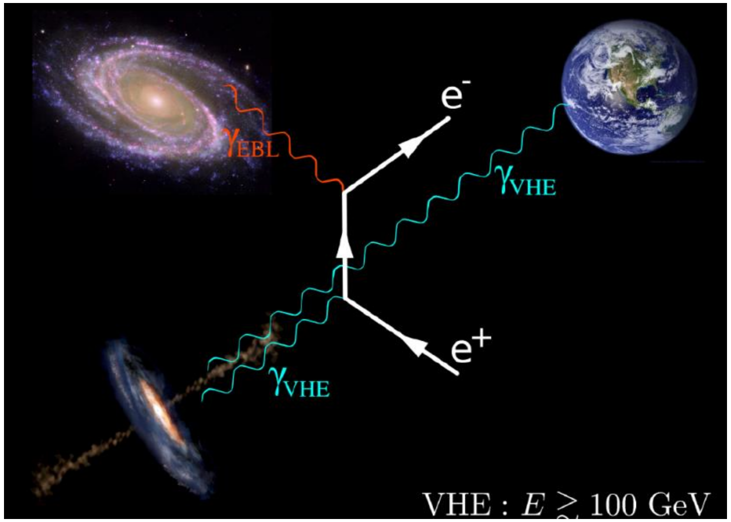

Particular interesting:

- ALP-photon couplings around $10^{-11}$GeV$^{-1}$, masses below 1 meV. Physics at a scale of $10^5$ TeV will be probed.

# Indications for a WISP world?

## Probe the transparency of the universe!

- GeV photons have a mean free pathlength comparable to the size of the universe.
- 100 GeV to TeV photons travel just about 100 Mpc, because they interact with extragalactic background light.



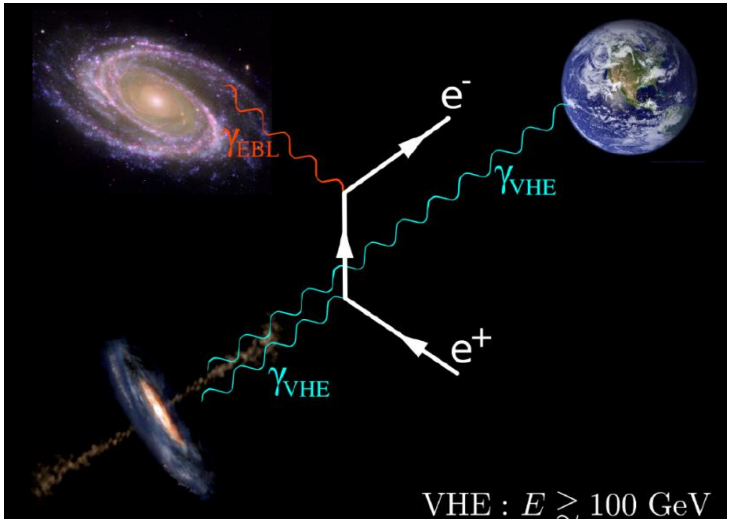

Center of mass energy about 1 MeV!

M. Meyer, 7th Patras Workshop on Axions, WIMPs and WISPs, 2011

# Indications for a WISP world?

## Probe the transparency of the universe!

- GeV photons have a mean free pathlength comparable to the size of the universe.
- 100 GeV to TeV photons **should** travel just about 100 Mpc, because they **should** interact with extragalactic background light.

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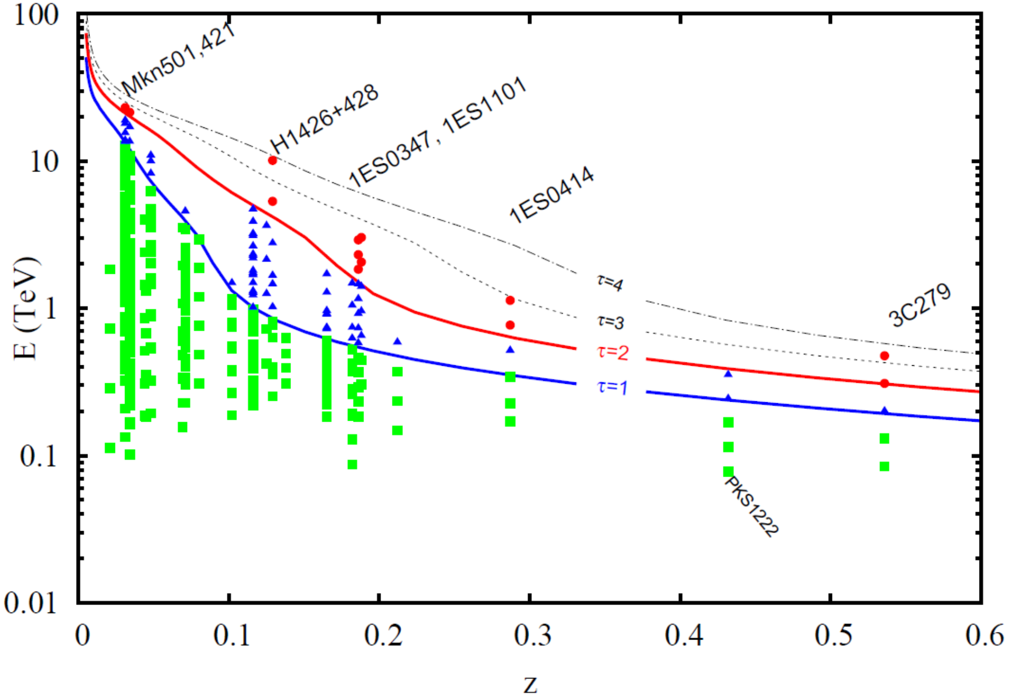
# Indications for a WISP world?

## However:

- The expected propagation of TeV photons seems to be in conflict with observations:

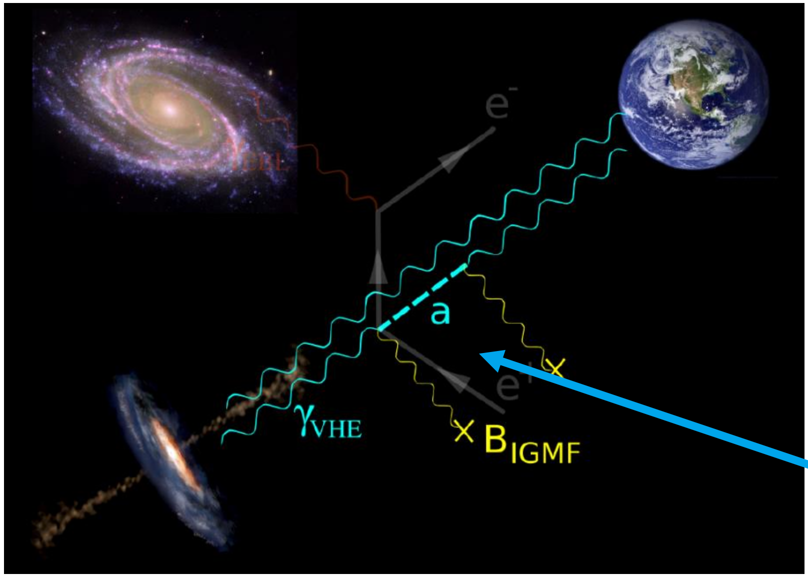



D. Horns, M. Meyer, JCAP 1202 (2012) 033

- If physics beyond the SM is involved, it shows up around the MeV scale!

# Indications for a WISP world?

- Axion-like particles might explain the apparent transparency of the universe for TeV photons:




M. Meyer, 7th Patras Workshop on Axions, WIMPs and WISPs, 2011

TeV photons may "hide" as ALPs: compare the ALPS II experiment at DESY!

# ALPs and cosmic TeV photons

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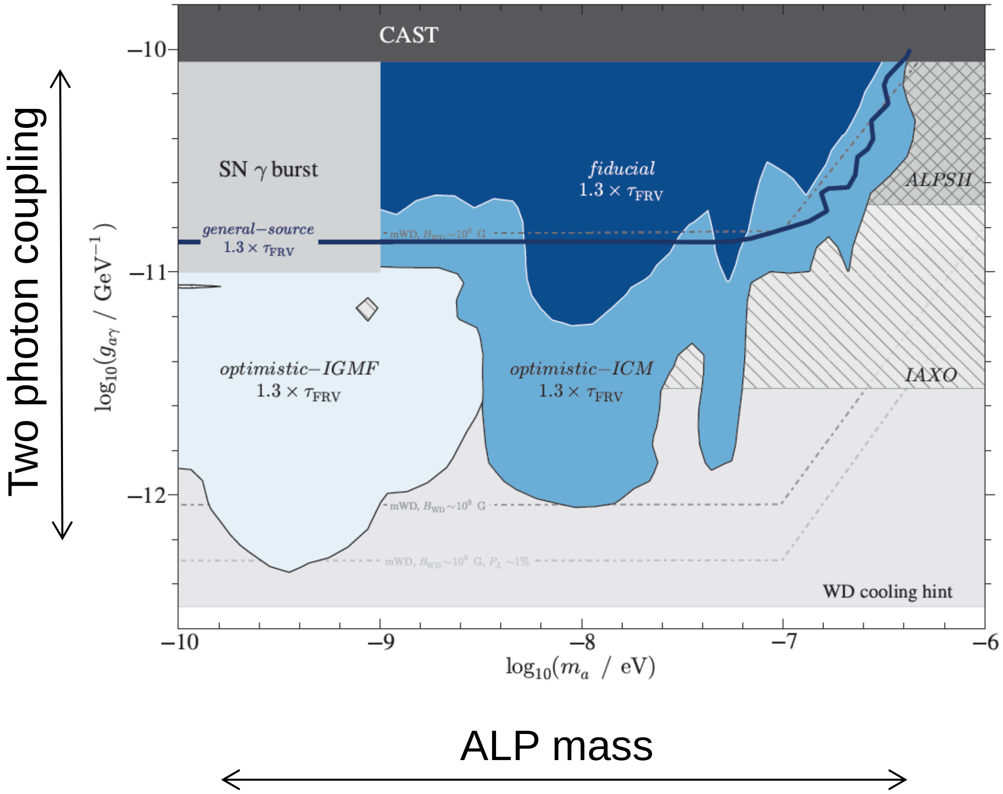


significance above 3.5 σ

$g_{a\gamma} \approx 10^{-11}\,\mathrm{GeV}^{-1}$, $m_a < 10^{-7}\,\mathrm{eV}$ have to be probed!

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

# ALPs and cosmic TeV photons

- New analysis including blazar spectra recorded by FERMI:

Pis'ma v ZhETF, vol. 100, iss. 6, pp. 397 – 401 © 2014 September 25

**Breaks in gamma-ray spectra of distant blazars and transparency of the Universe**[1)]

*G. I. Rubtsov, S. V. Troitsky*[2)]

*Institute for Nuclear Research of the RAS, 117312 Moscow, Russia*

arXiv:1406.0239 [astro-ph.HE]

- Significance about 12 σ!

"*While detailed tests of these scenarios versus our results will be presented elsewhere, our preliminary considerations thus favour the ALP convertion / reconvertion scenario for the explanation of the effect we observe.*"

# WISPs all around us?

- If WISP exist, they are light enough to be produced in stars.
- If WISP exist, they might influence stellar evolutions or show up at other astrophysics phenomena.

- One should look for “new physics” at low energy scales!

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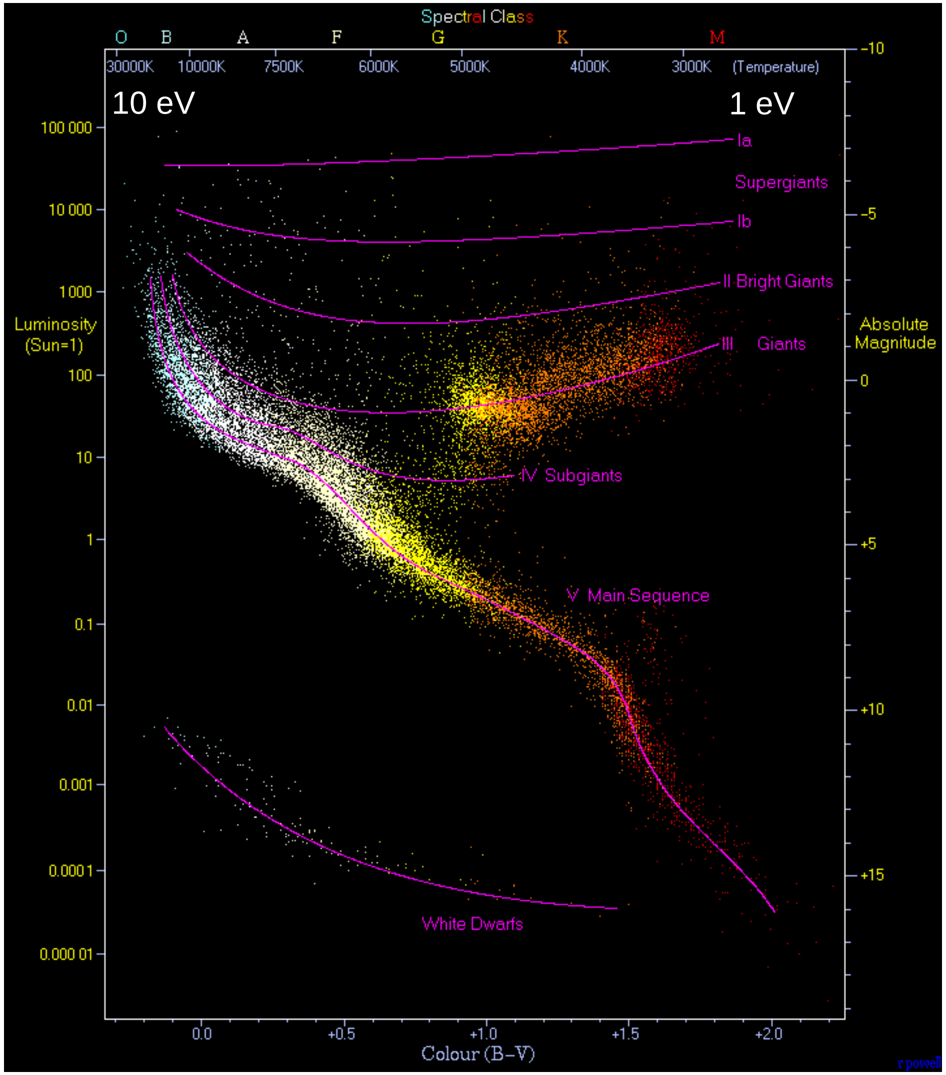


http://en.wikipedia.org/wiki/Hertzsprung%E2%80%93Russell_diagram

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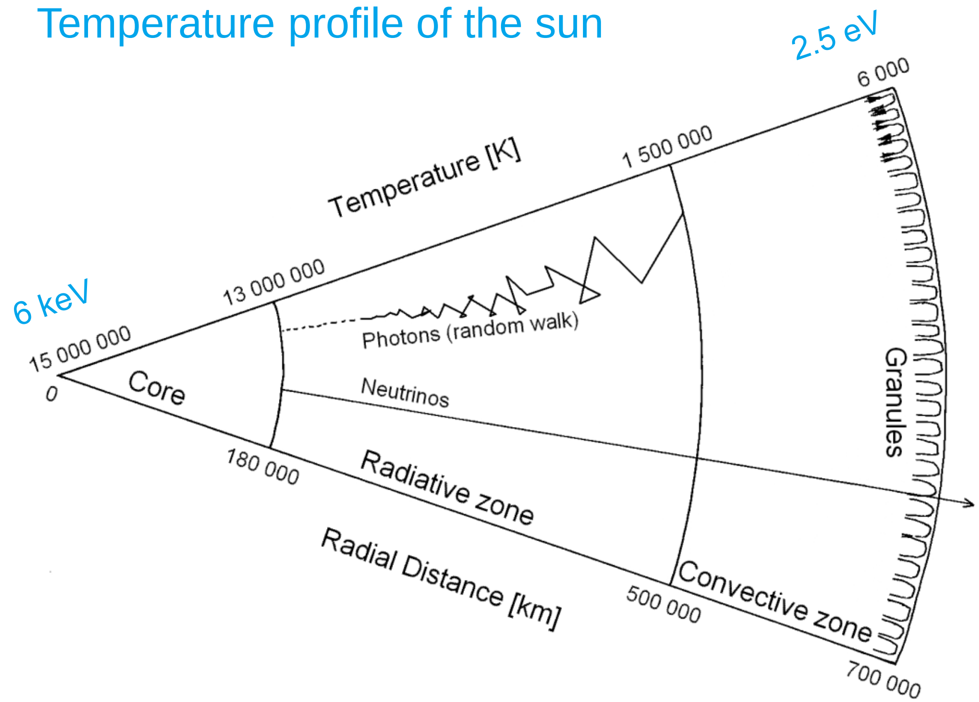
Temperature profile of the sun




arXiv:1307.2410 [astro-ph.SR]

# More (vague) hints for ALPs?

- Additional energy losses beyond SM physics in globular cluster stars and white dwarfs?
- Indications for a Cosmic ALP background (CAB)?

| Phenomenon | ALP mass [eV] | ALP-$\gamma$ coupl. [$GeV^{-1}$] | Reference |
|---|---|---|---|
| TeV transparency | $< 10^{-7}$ | $> 10^{-11}$ | arXiv:1302.1208 [astro-ph.HE] |
| Globular cluster stars (HB) | $< 10^{4}$ | $\approx 5{\cdot}10^{-11}$ | arXiv:1406.6053 [astro-ph.SR] |
| CAB (Coma Cluster) | $< 10^{-13}$ | $10^{-12}$ to $10^{-13}$ | arXiv:1406.5188 [hep-ph] |
| White dwarfs | $< 10^{-2}$ | $(g_{ae} \approx 5{\cdot}10^{-13})$ | arXiv:1304.7652 [astro-ph.SR] |

- There are allowed regions in parameter space where an ALP can simultaneously explain the gamma ray transparency, the cooling of HB stars, and the soft X-ray excess from Coma and be a subdominant contribution to CDM.

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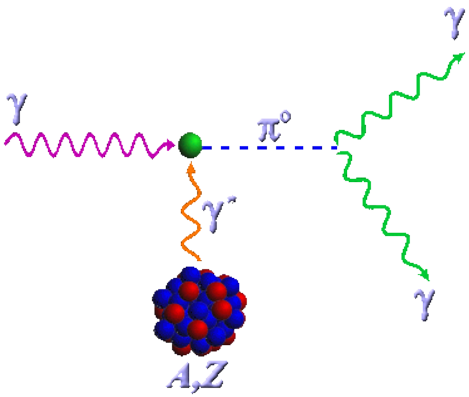
- Therefore the Primakoff effect will also work for the axion!



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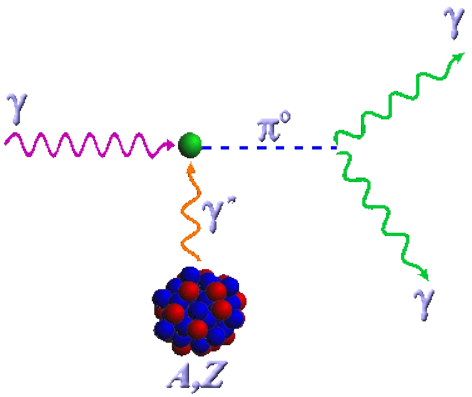
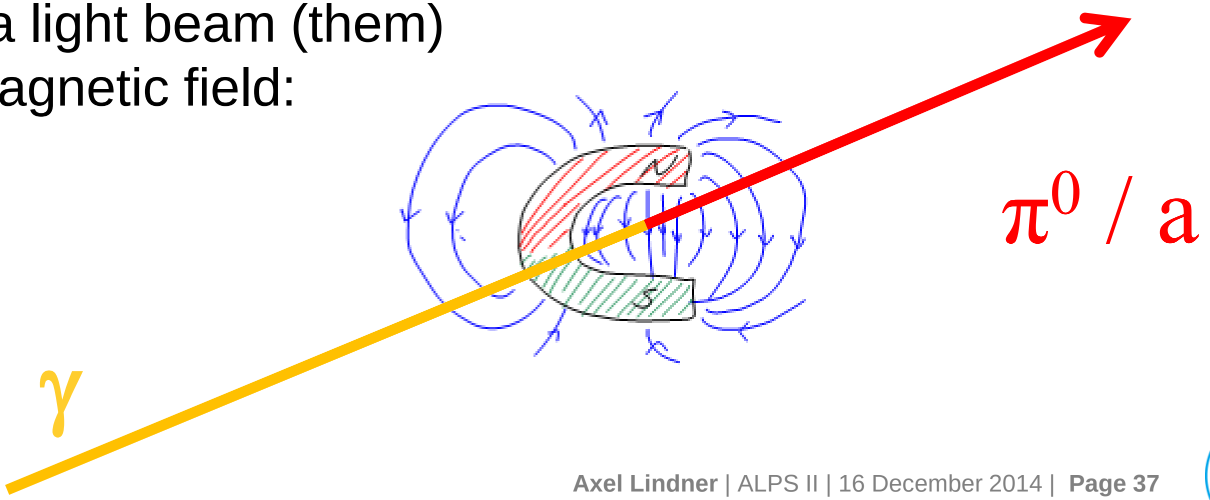


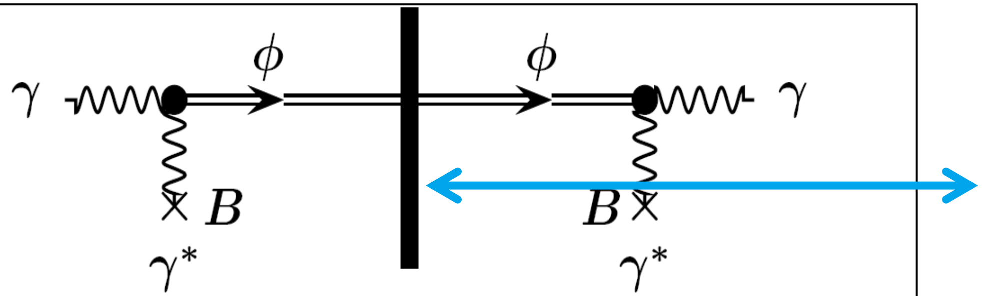

- Axions could be produced (detected) by sending a light beam (them) through a magnetic field:



# Basics of WISP experiments (I)

- Basic idea: due to their very weak interaction WISPs may traverse any wall opaque to Standard Model constituents (except ν and gravitons).
  - WISP could transfer energy out of a shielded environment
  - WISP could convert back into detectable photons behind a shielding.

- “Light-shining-through-a-wall” (LSW)




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

steel wall, cryostat,
earth’s atmosphere,
stellar body,
intergalactic background light,
….

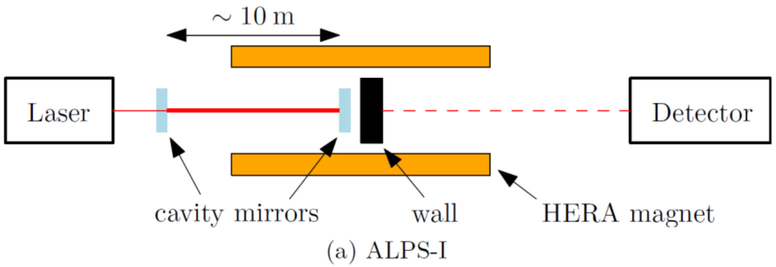


DESY

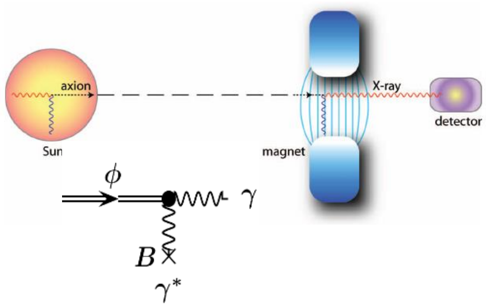
# Three kinds of WISP searches

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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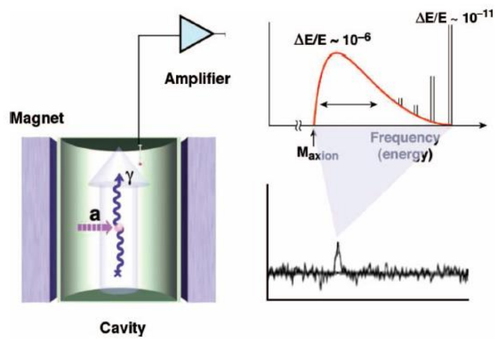

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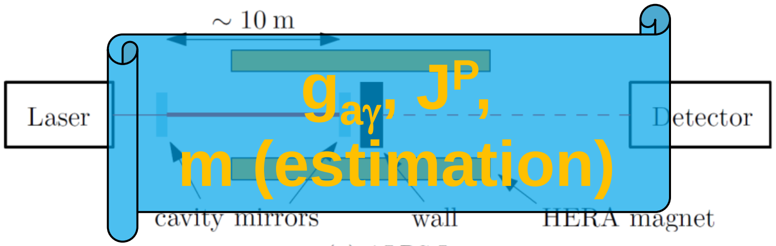


(a) ALPS-I

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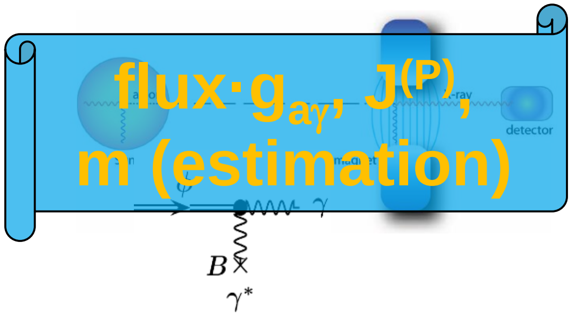


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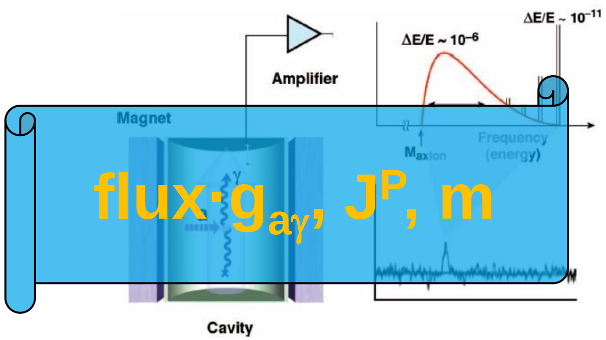

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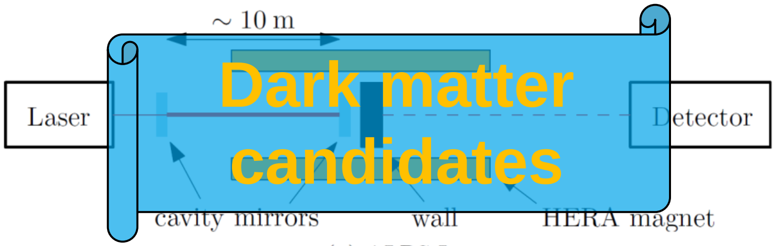


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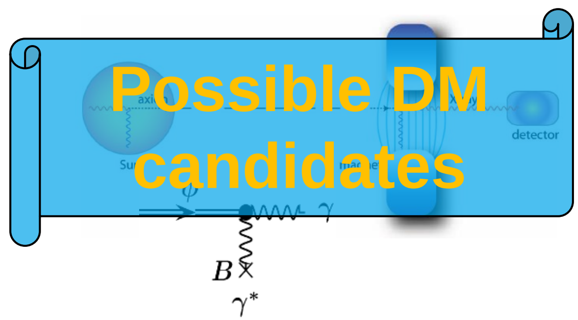


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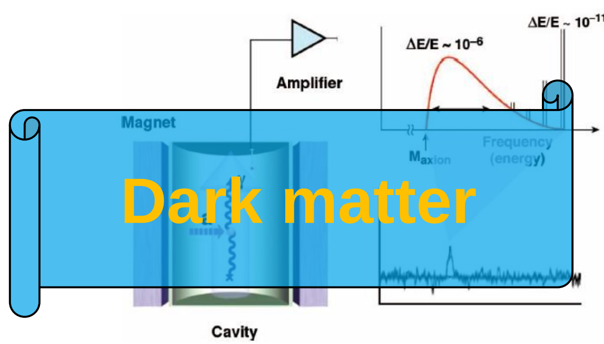

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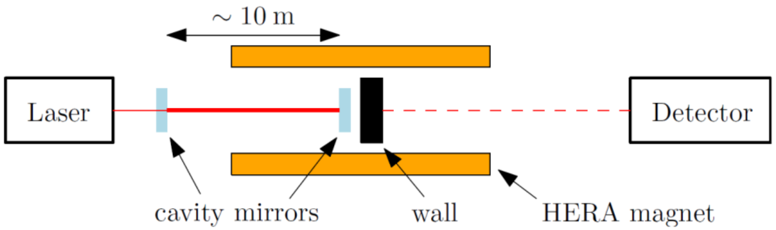


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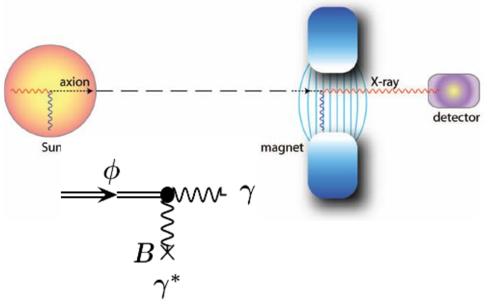


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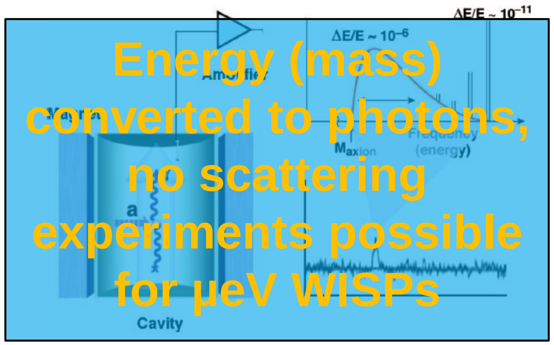

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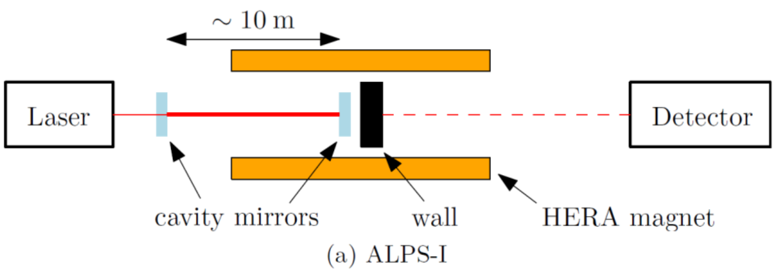


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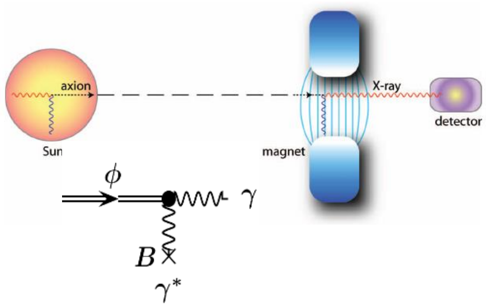


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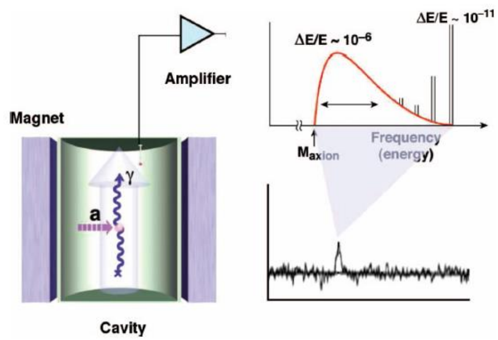


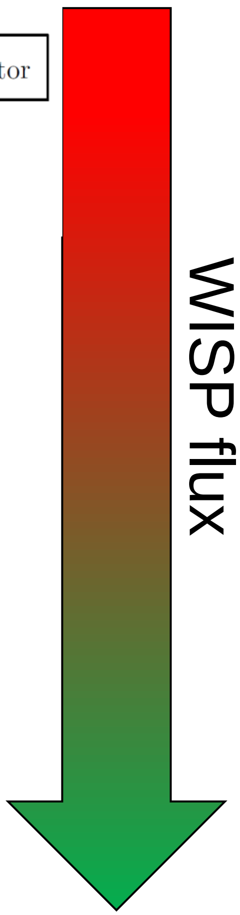

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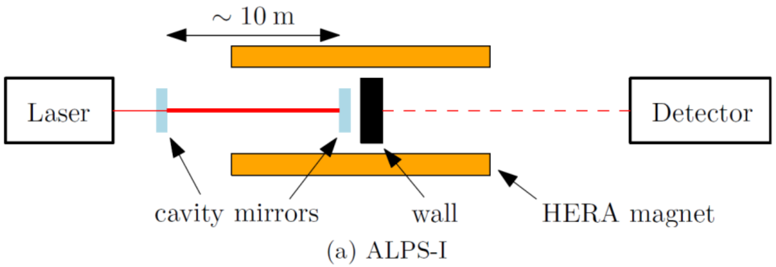


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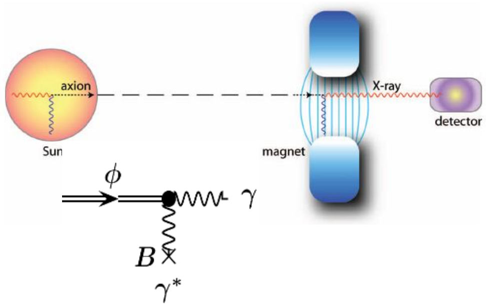


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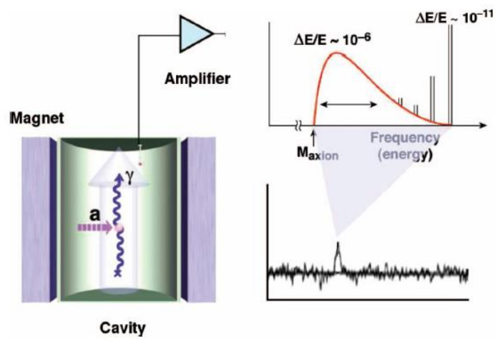


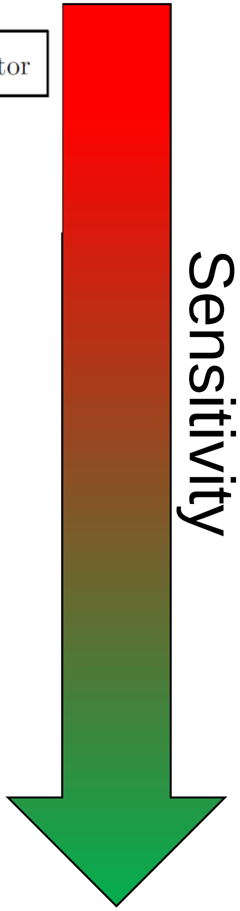

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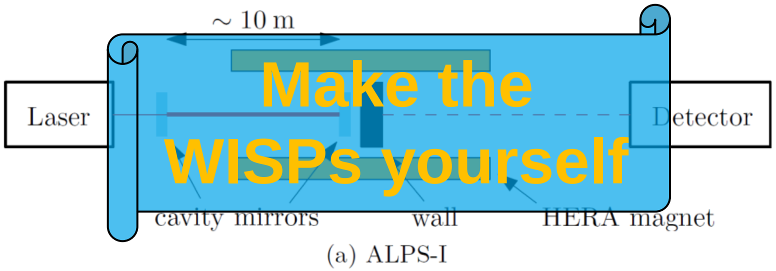


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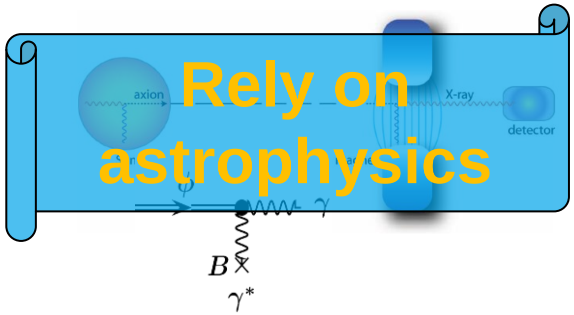


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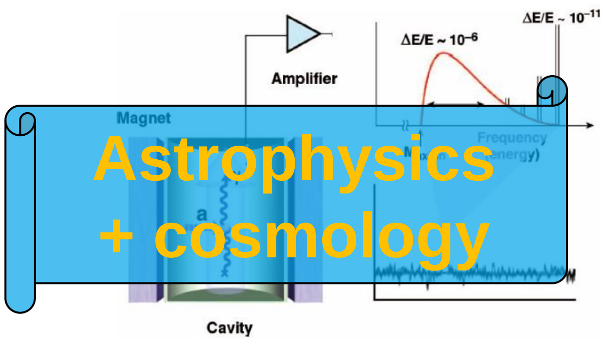

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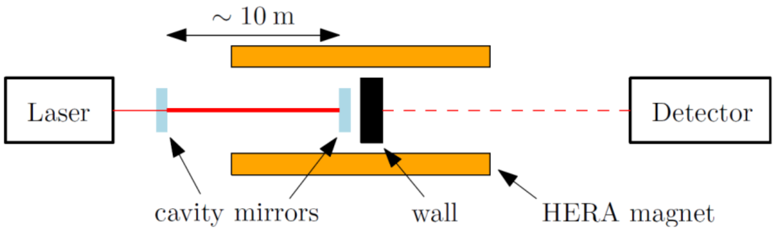


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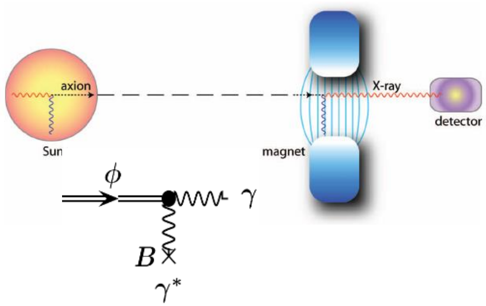


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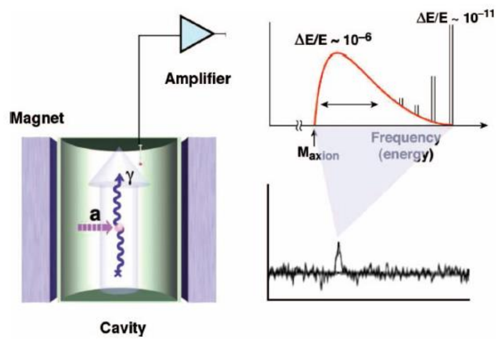


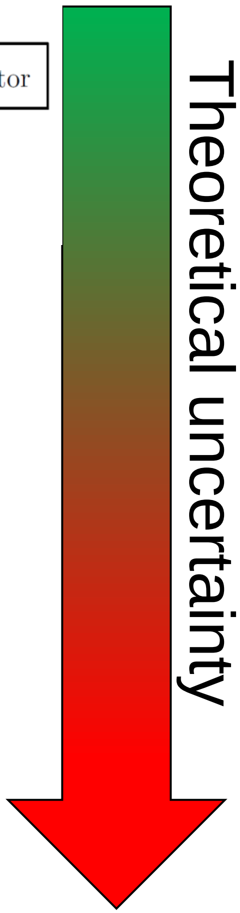

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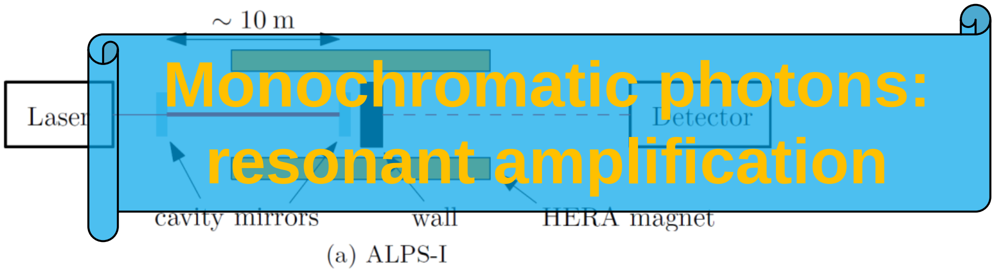


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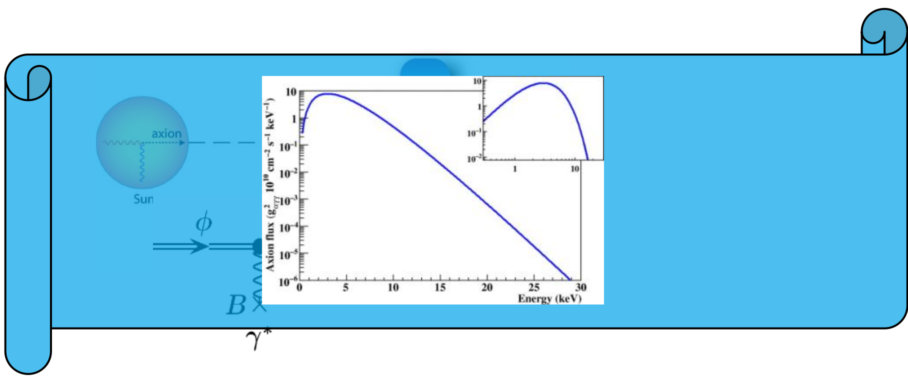


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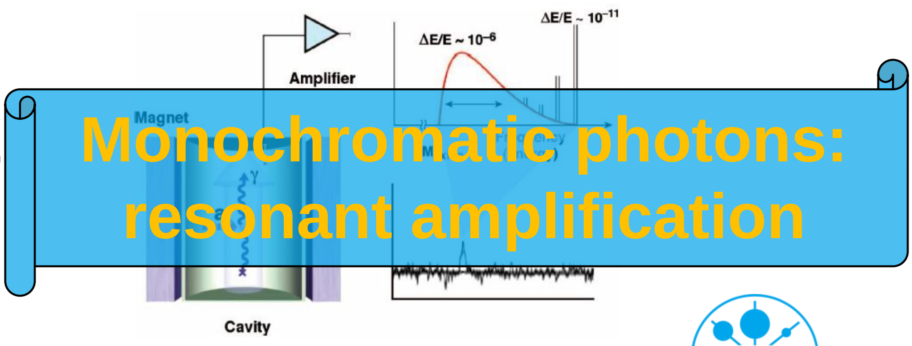

# WISP experiments worldwide

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

| Experiment | Type | Location | Status |
|---|---|---|---|
| ALPS II | Laboratory experiments, light-shining-through-a-wall | DESY | preparation |
| CROWS | | CERN | finished |
| OSQAR | | CERN | running |
| REAPR | | FNAL | proposed |
| CAST | Helioscopes | CERN | running |
| IAXO | | ? | proposed |
| SUMICO | | Tokyo | finished (?) |
| TSHIPS | | Hamburg | finished |
| ADMX | Haloscope | Seattle, NH | running |
| FUNK | | KIT Karlsruhe | studies |
| WISPDMX | | DESY in HH | studies |

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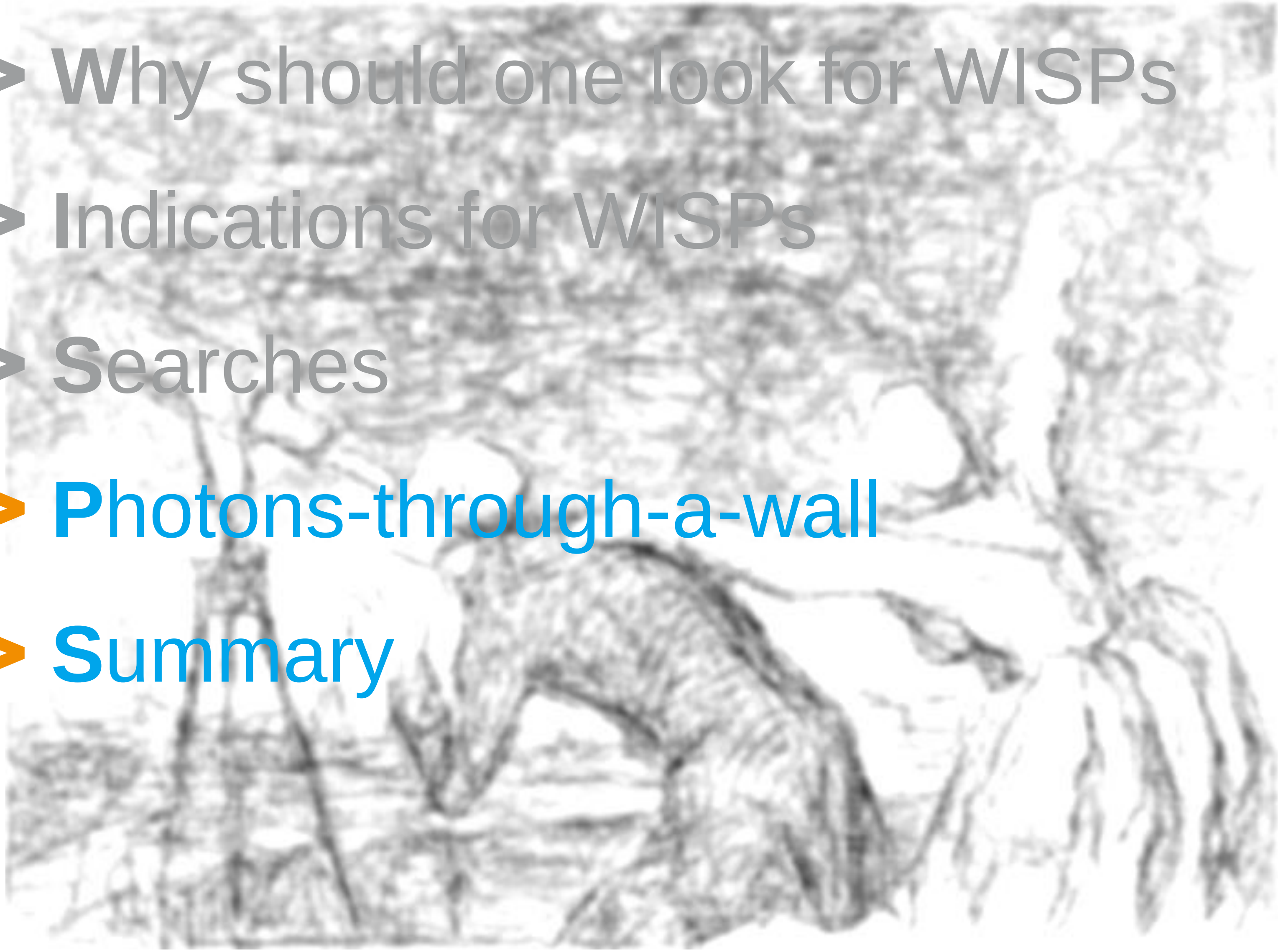
# Outline



- Why should one look for WISPs
- Indications for WISPs
- Searches
- Photons-through-a-wall
- Summary

# ALPS I at DESY in Hamburg

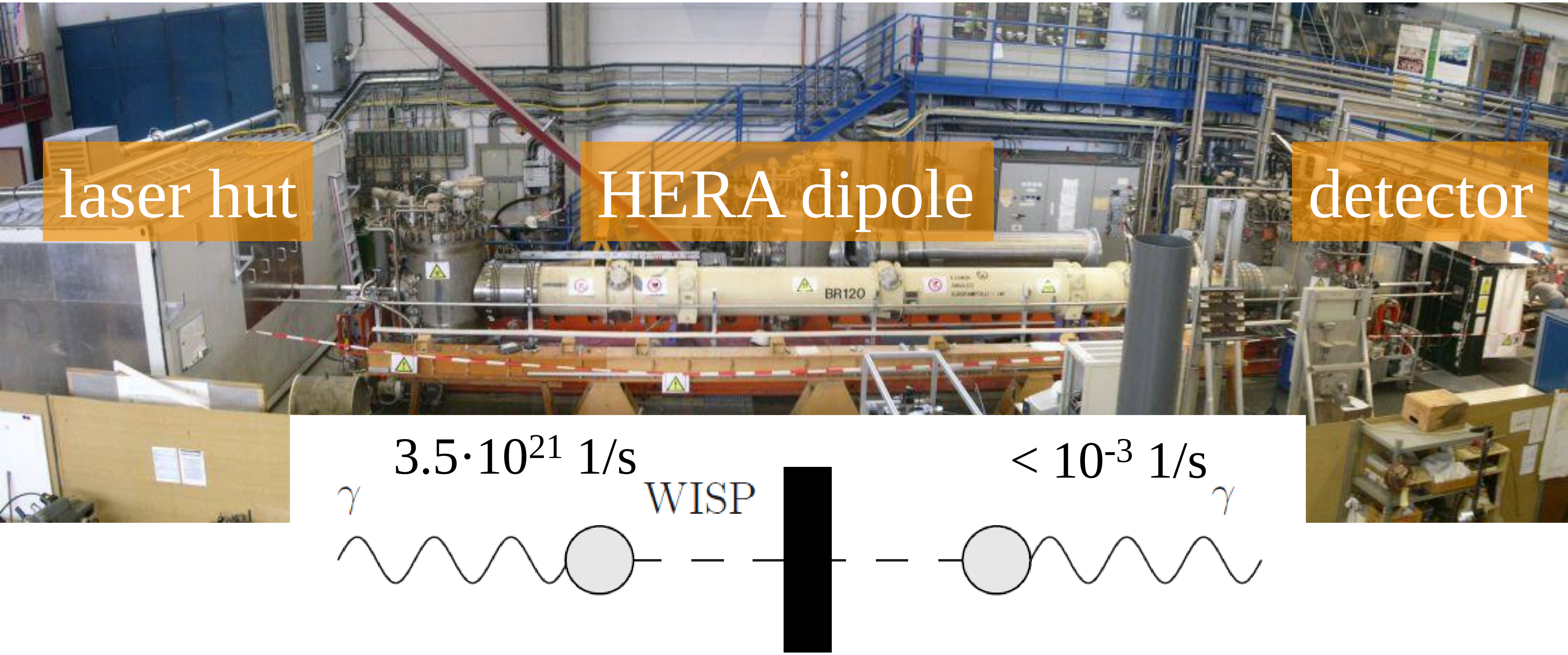
Any Light Particle Search @ DESY: ALPS I


Approved in 2007, concluded in 2010

# ALPS I results

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

- Unfortunately, no light was shining through the wall!




- The most sensitive WISP search experiment in the laboratory (nearly).

# 2013: CERN microwave experiment

PHYSICAL REVIEW D **88,** 075014 (2013)

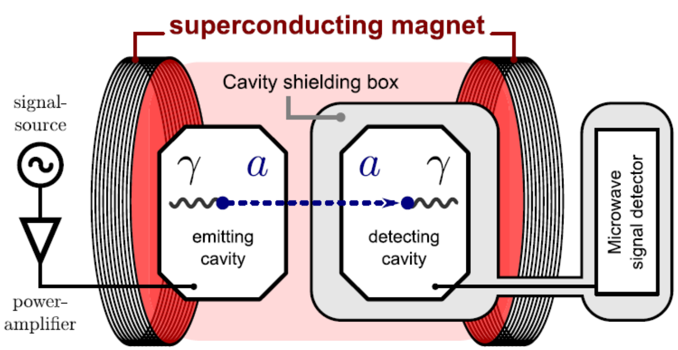
**First results of the CERN Resonant Weakly Interacting sub-eV Particle Search (CROWS)**

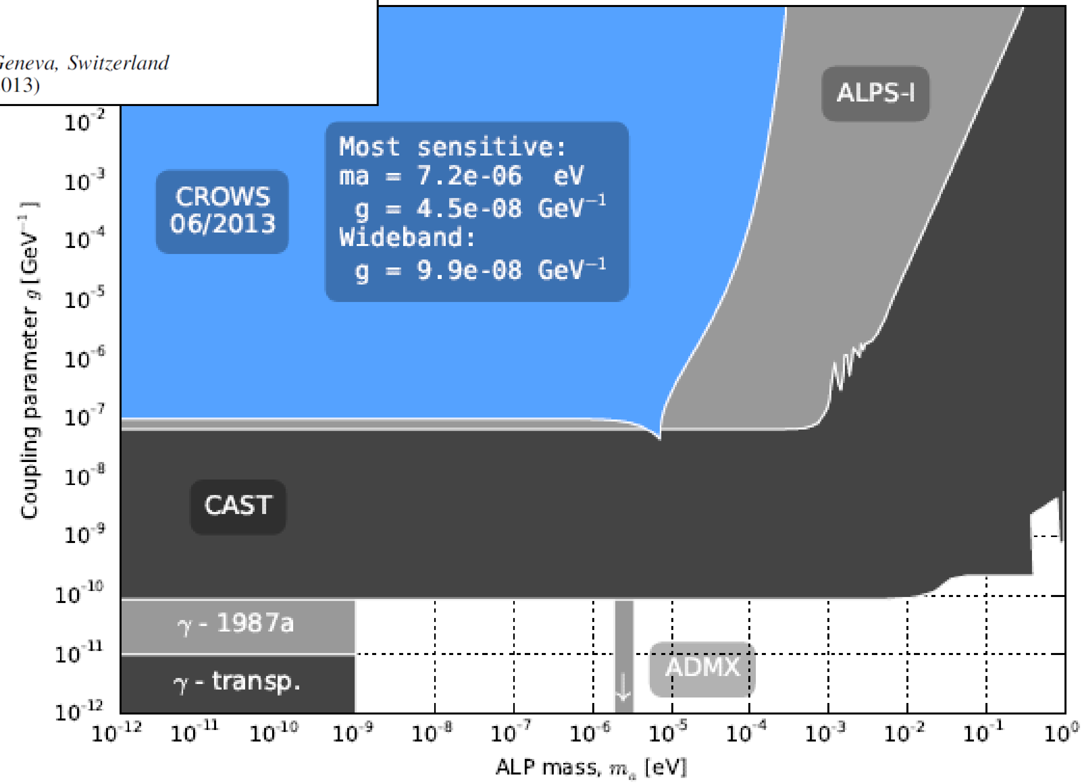
M. Betz, F. Caspers, and M. Gasior
*Beams Department, CERN, CH-1211 Geneva, Switzerland*

M. Thumm
*Institute for Pulsed Power and Microwave Technology and Institute of High Frequency Techniques and Electronics, Karlsruhe Institute of Technology (KIT), Kaiserstraße 12, 76131 Karlsruhe, Germany*

S. W. Rieger
*Brain & Behaviour Laboratory, University of Geneva, CH-1211 Geneva, Switzerland*

(Received 13 August 2013; published 24 October 2013)



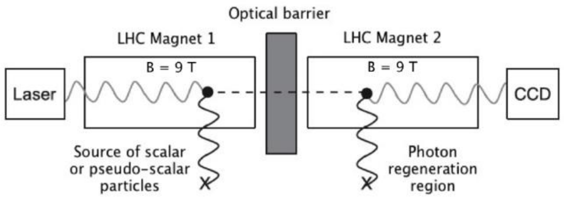



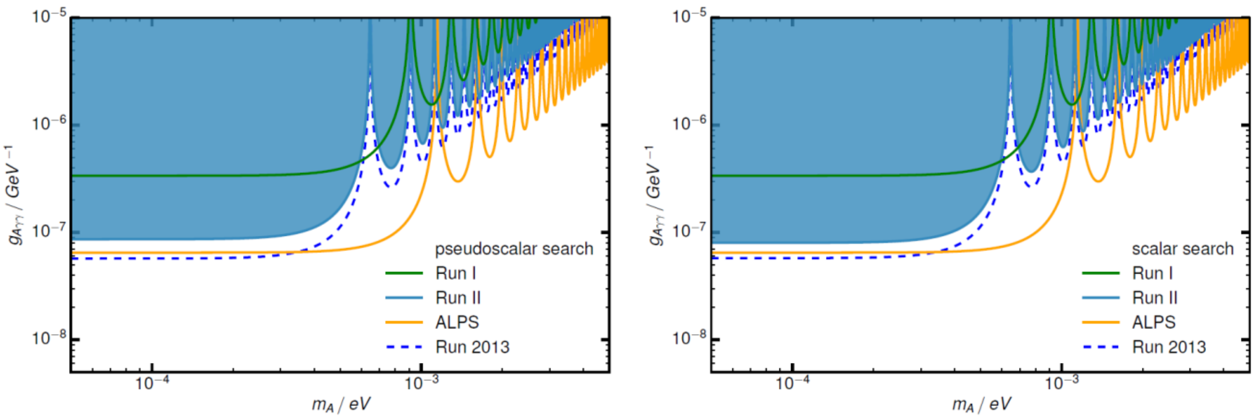
# 2014: OSQAR at CERN

**Latest Results of the OSQAR Photon Regeneration Experiment for Axion-Like Particle Search**

*Rafik Ballou[1,2], Guy Deferne[3], Lionel Duvillaret[4], Michael Finger, Jr.[5], Miroslav Finger[5], Lucie Flekova[5], Jan Hosek[6], Tomas Husek[5], Vladimir Jary[6], Remy Jost[7,8], Miroslav Kral[6], Stepan Kunc[9], Karolina Macuchova[6], Krzysztof A. Meissner[10], Jérôme Morville[11,12], Pierre Pugnat[13,14], Daniele Romanini[7,8], Matthias Schott[15], Andrzej Siemko[3], Miloslav Slunecka[5], Miroslav Sulc[9], Guy Vitrant[4], Christoph Weinsheimer[15], Josef Zicha[6]*

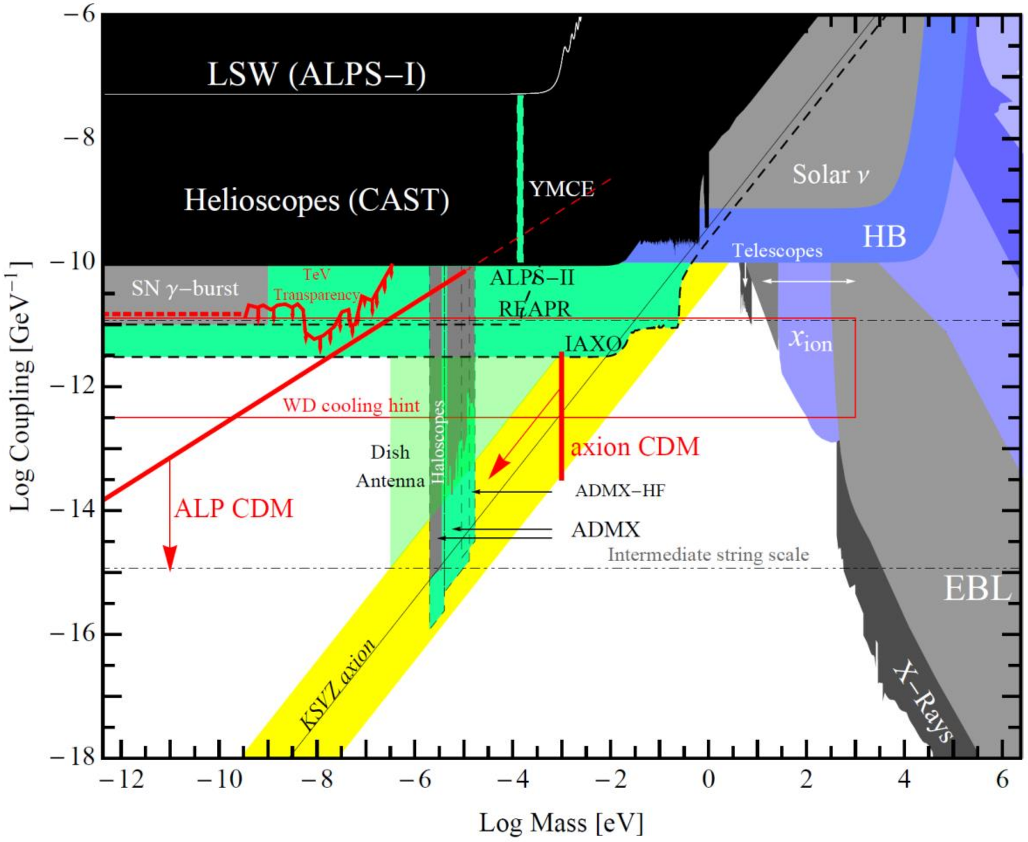
arXiv:1410.2566 [hep-ex]



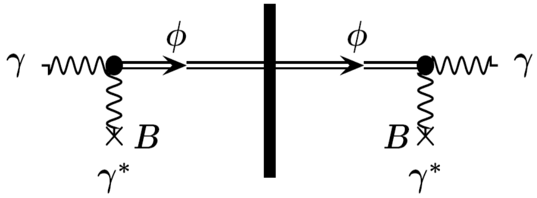




- With **two LHC dipoles** OSQAR has surpassed the ALPS I sensitivity.
- No evidence for axion-like particles has been found (as expected from other exclusion limits).

# The LSW challenge




Improve the sensitivity by three orders of magnitude!




Note:
the experiment measures $g^4$!

Hence the sensitivity of the experiment is to be increased by $10^{12}$!

# 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 $P_{\text{laser}}$ | $g_{a\gamma} \propto P_{\text{laser}}^{-1/4}$ | $1\,\text{kW}$ | $150\,\text{kW}$ | 3.5 |
| Rel. photon number flux $n_\gamma$ | $g_{a\gamma} \propto n_\gamma^{-1/4}$ | 1 (532 nm) | 2 (1064 nm) | 1.2 |
| Power built up in RC $P_{\text{RC}}$ | $g_{a\gamma} \propto P_{reg}^{-1/4}$ | 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 $DC$ | $g_{a\gamma} \propto DC^{1/8}$ | $0.0018\,\text{s}^{-1}$ | $0.000001\,\text{s}^{-1}$ | 2.6 |
| Combined improvements | | | | 3082 |

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

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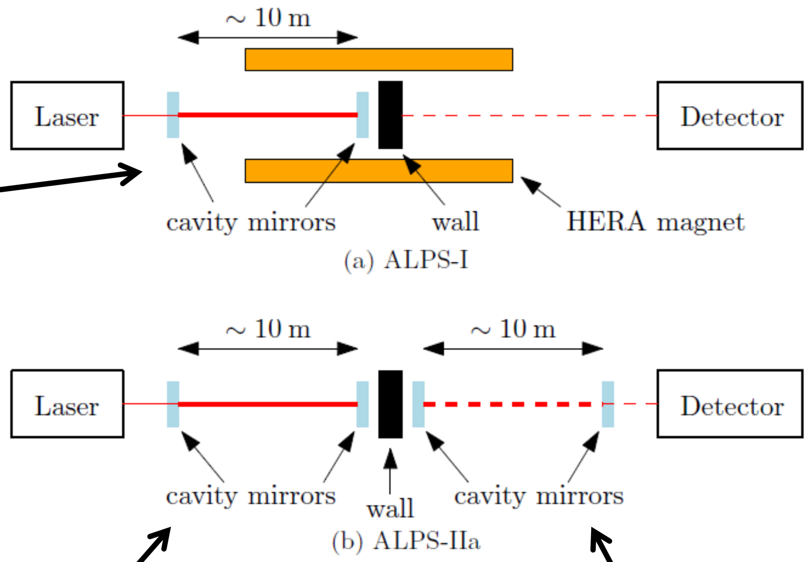
DESY

# ALPS II essentials: laser & optics

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




> **ALPS IIa**

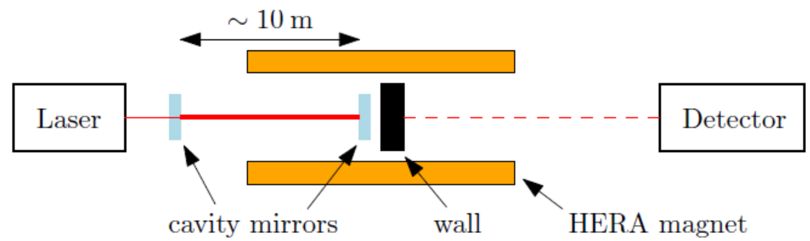
Optical resonator to increase effective light flux by recycling the laser power

Optical resonator to increase the conversion probability
WISP→γ

First realization of a 23 year old proposal!

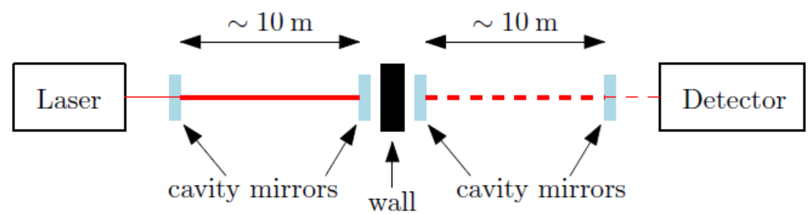
# ALPS II is realized in stages

ALPS I



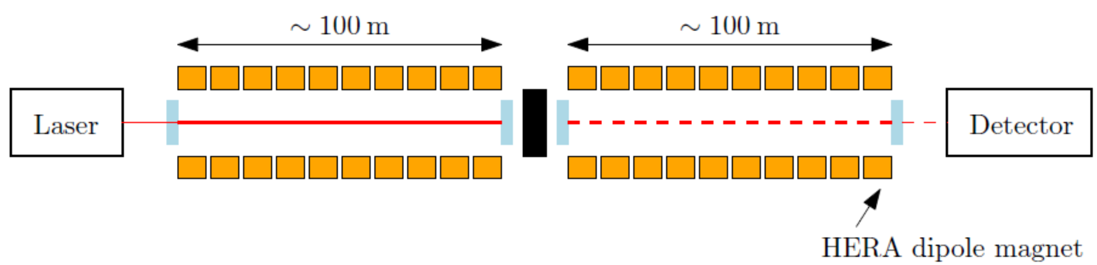

(a) ALPS-I

> **ALPS IIa**




(b) ALPS-IIa

> **ALPS IIc**




(d) ALPS-IIc

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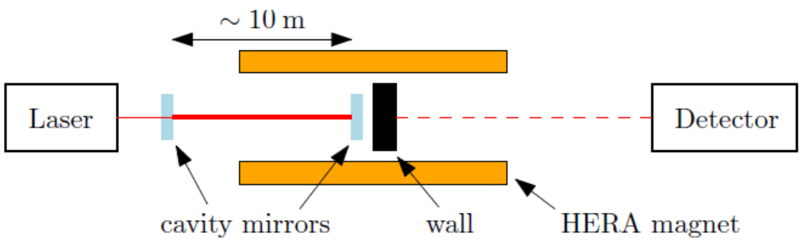
ALPS I

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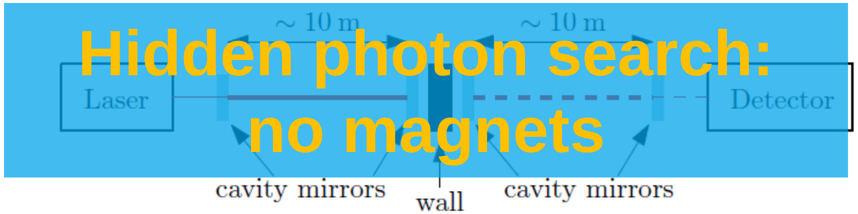


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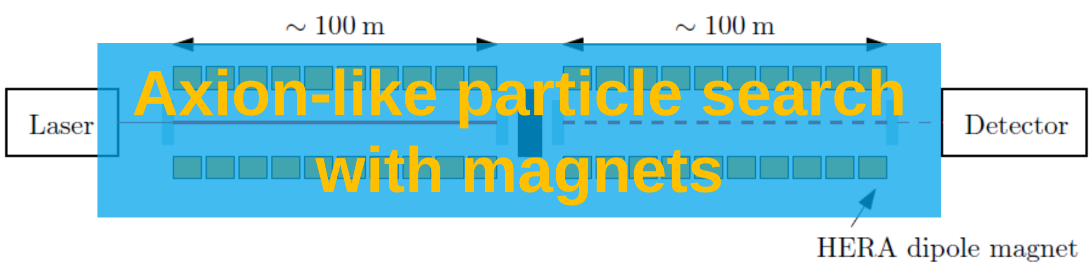
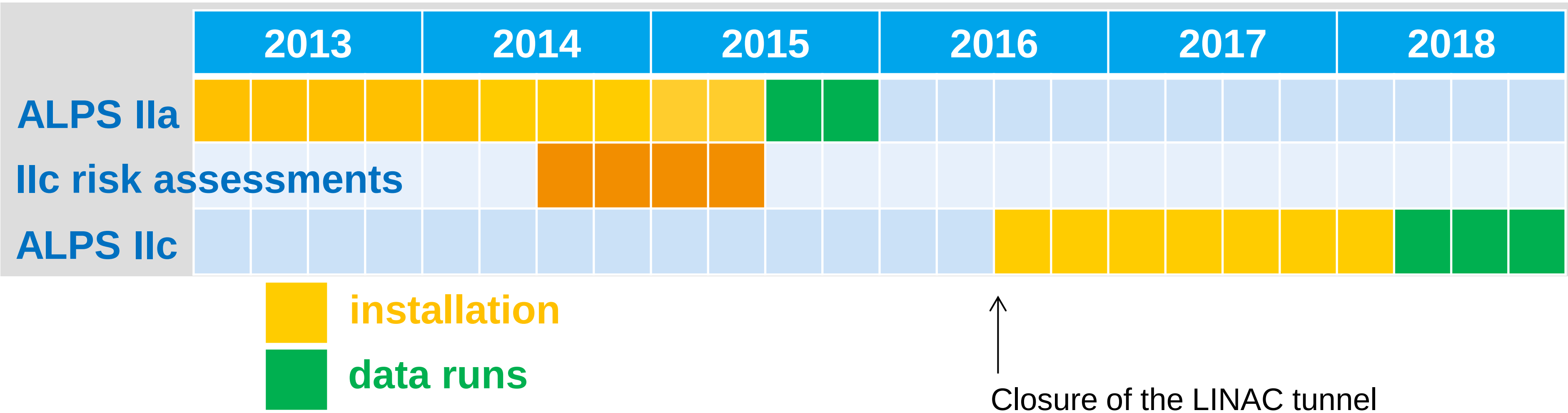



(d) ALPS-IIc

# ALPS II schedule (rough)



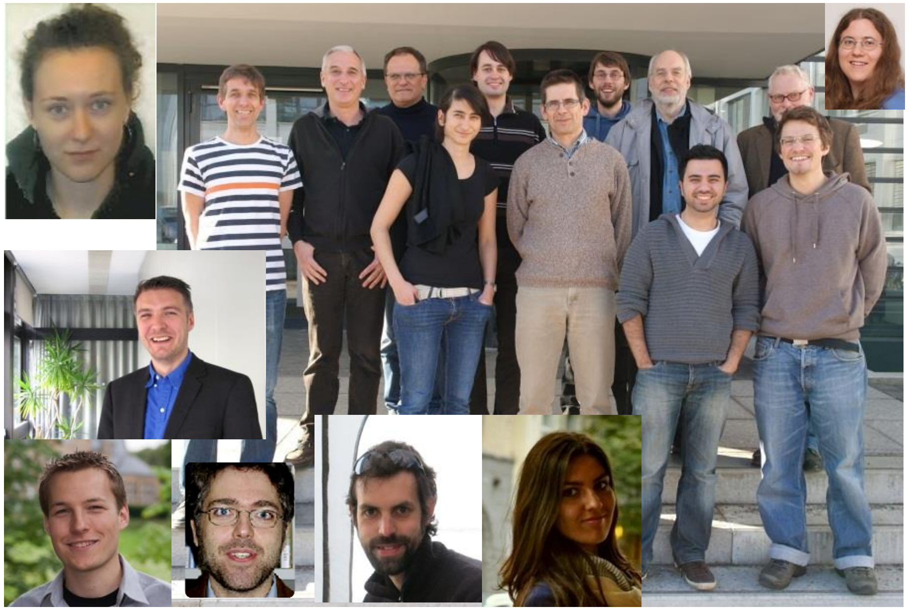

Closure of the LINAC tunnel
of the European XFEL project
under construction at DESY.

ALPS IIc in 2018
in the HERA tunnel

# The collaboration: PhDs and postdocs

ALPS II is a joint effort of

- DESY:
  Babette Döbrich, Jan Dreyling-Eschweiler, Samvel Ghazaryan,
  Reza Hodajerdi, Friederike Januschek, Ernst-Axel Knabbe, Natali Kuzkova, Axel Lindner,
  Andreas Ringwald, Jan Pöld, Jan Eike von Seggern, Richard Stromhagen, Dieter Trines
- Hamburg University:
  Noemie Bastidon, Dieter Horns
- AEI Hannover
  (MPG & Hannover Uni.):
  Robin Bähre, Benno Willke
- Mainz University:
  Matthias Schott, Christoph Weinsheimer

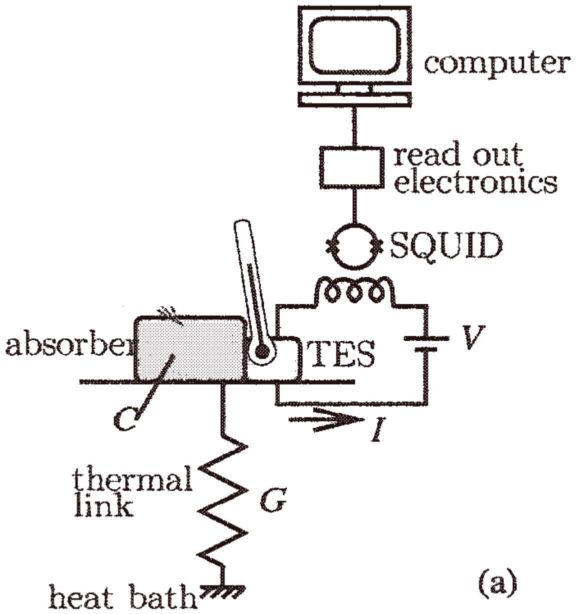


with strong support from

- neoLASE, PTB Berlin, NIST (Boulder)

# ALPS II detector

Transition Edge Sensor (TES)



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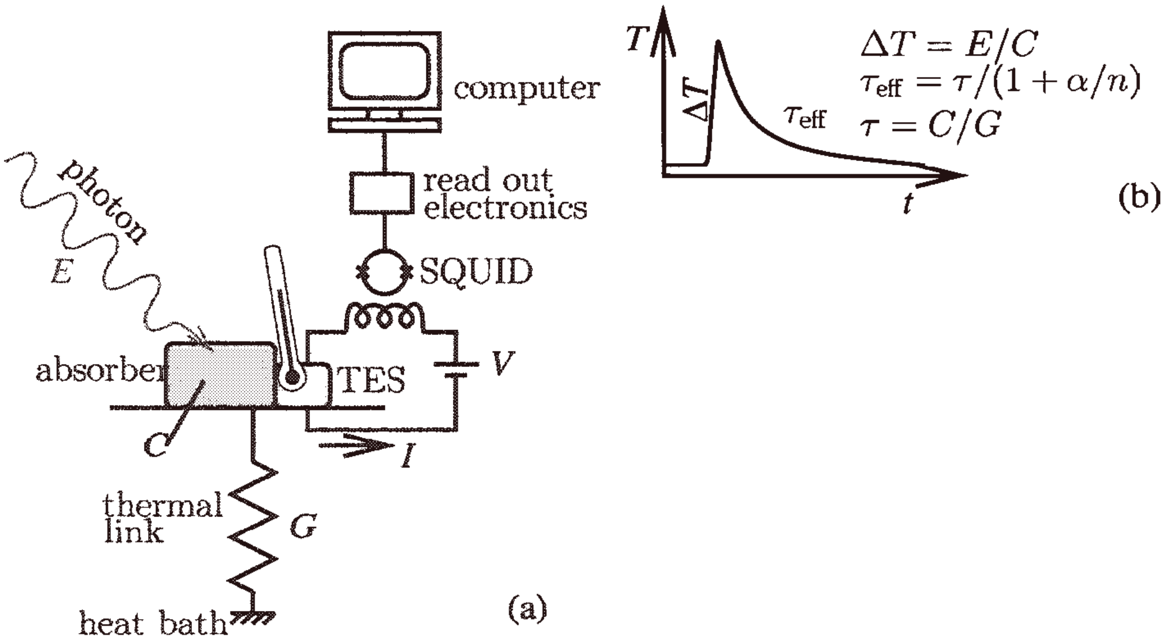

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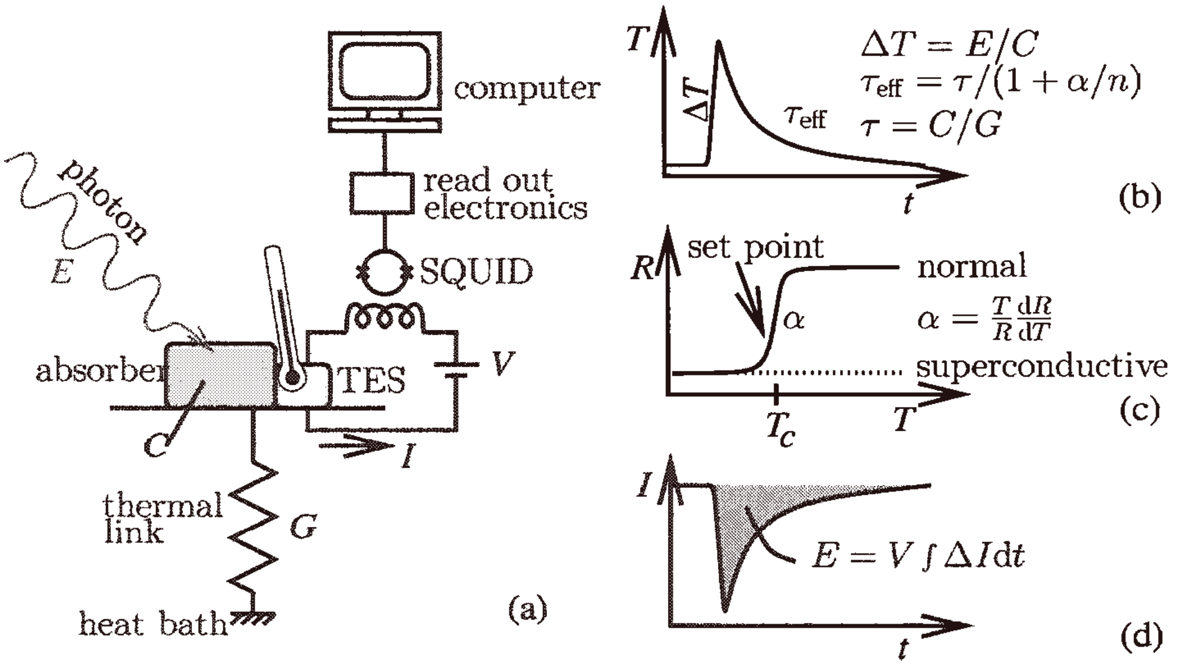
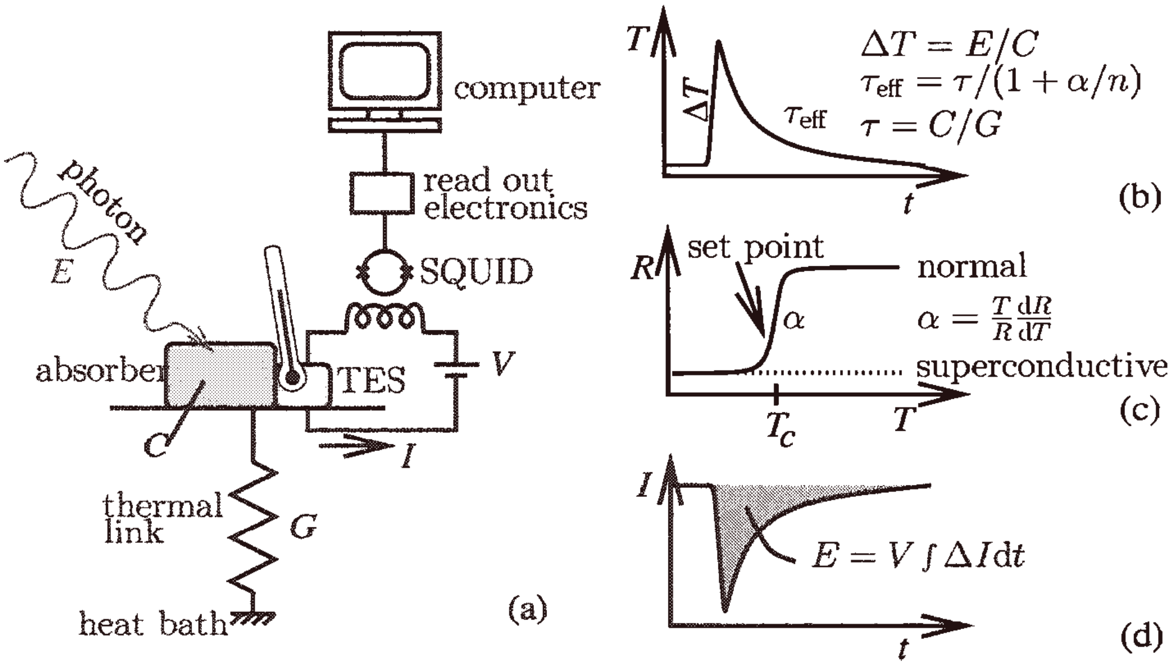


# ALPS II detector

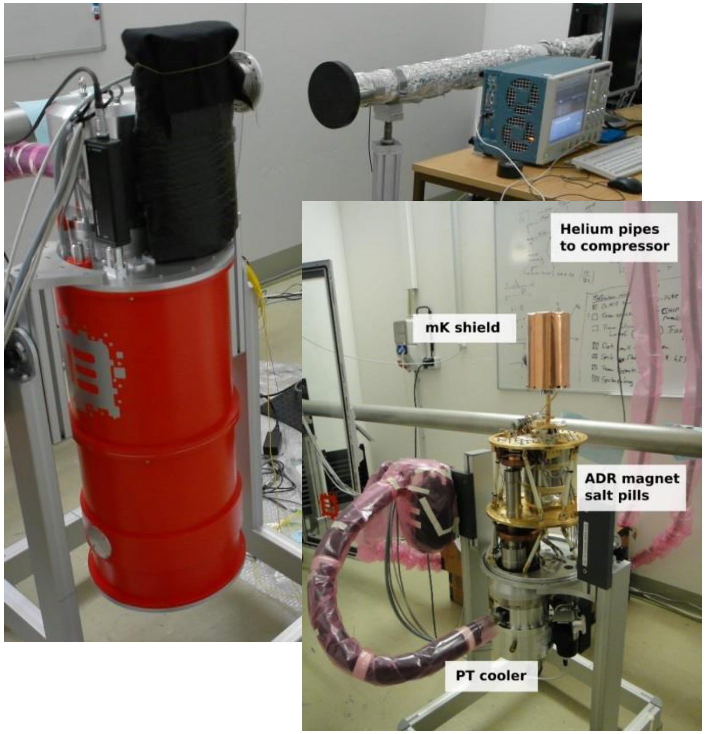
Transition Edge Sensor (TES)



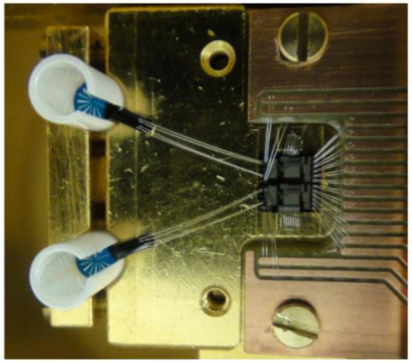

- Expectation:
  very high quantum efficiency, also at 1064 nm,
  very low noise.

# ALPS II: Transition Edge Sensor (TES)

- Tungsten film kept at the transition to superconductivity at 80 mK.
- Sensor size 25µm x 25µm x 20nm.




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



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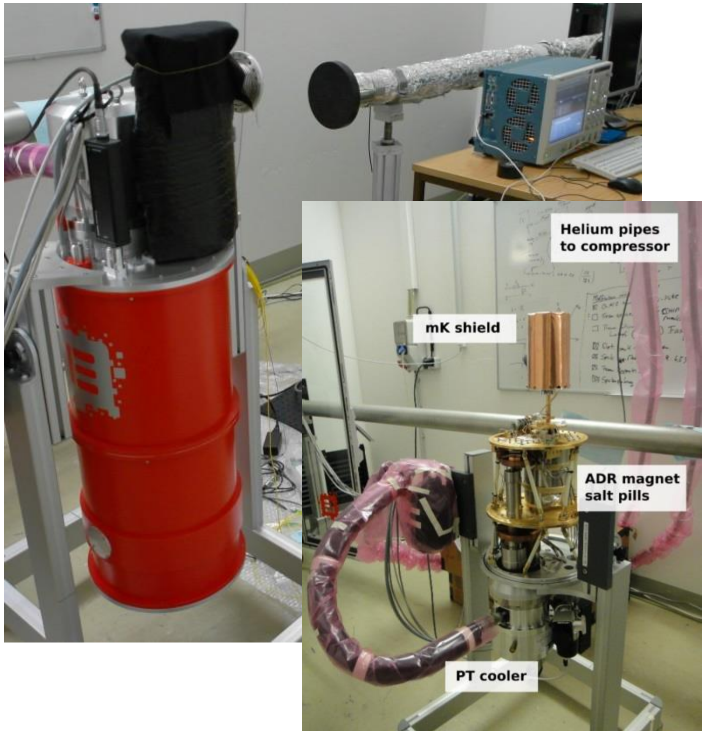


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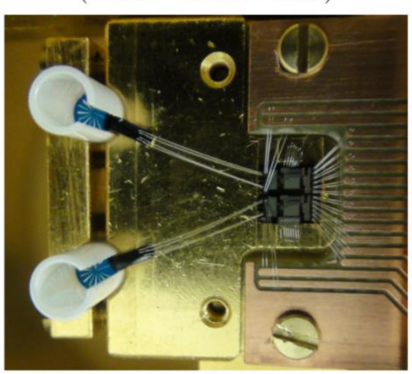

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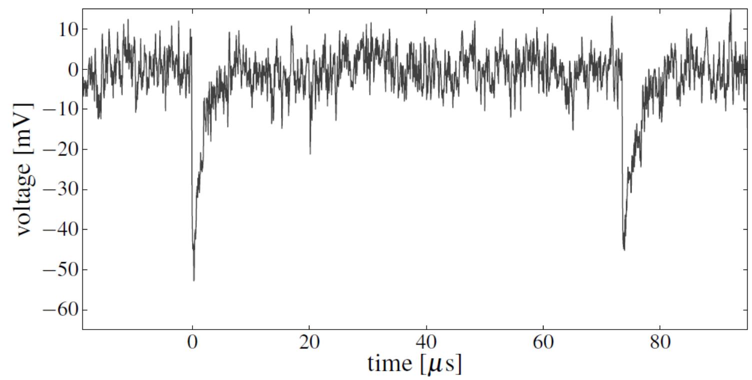
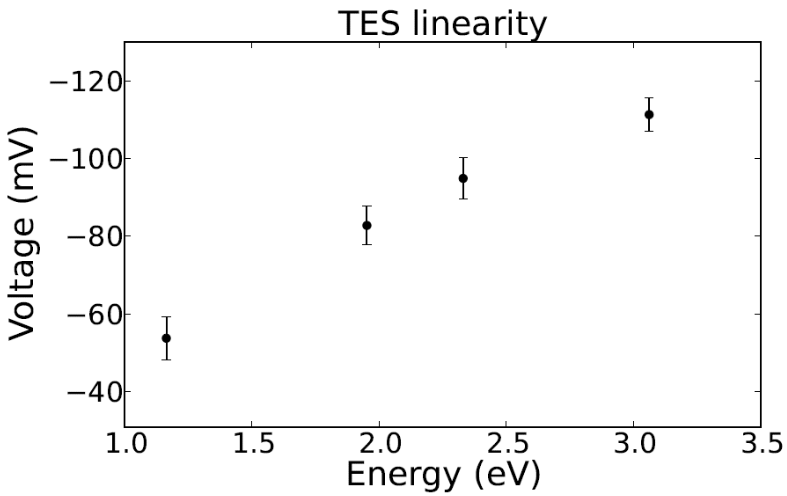



- Single 1066 nm photon pulses!
- Energy resolution ≈8%.
- Dark background $10^{-4}$ counts/second.
- Ongoing: background studies, optimize fibers, minimize background from ambient thermal photons.

# More selected TES results

(Thesis of J. Dreyling Eschweiler, paper submitted to the *Journal of Modern Optics*)

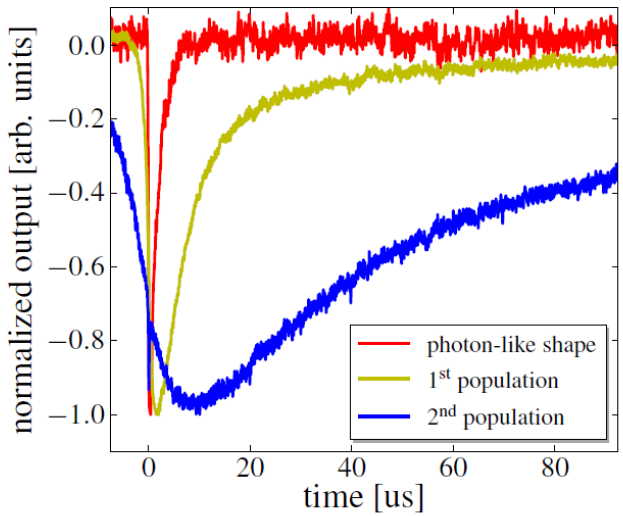
- The TES is linear and shows some saturation at higher energies as expected.
  The absolute energy resolution stays constant!

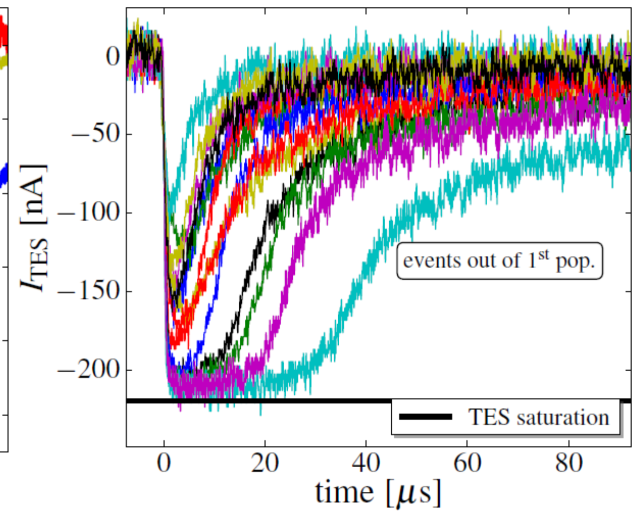


# More selected TES results

(Thesis of J. Dreyling Eschweiler, paper submitted to the *Journal of Modern Optics*)

- There is an intrinsic background most likely related to radioactivity and cosmic rays depositing energy in the silicon substrate around the TES.



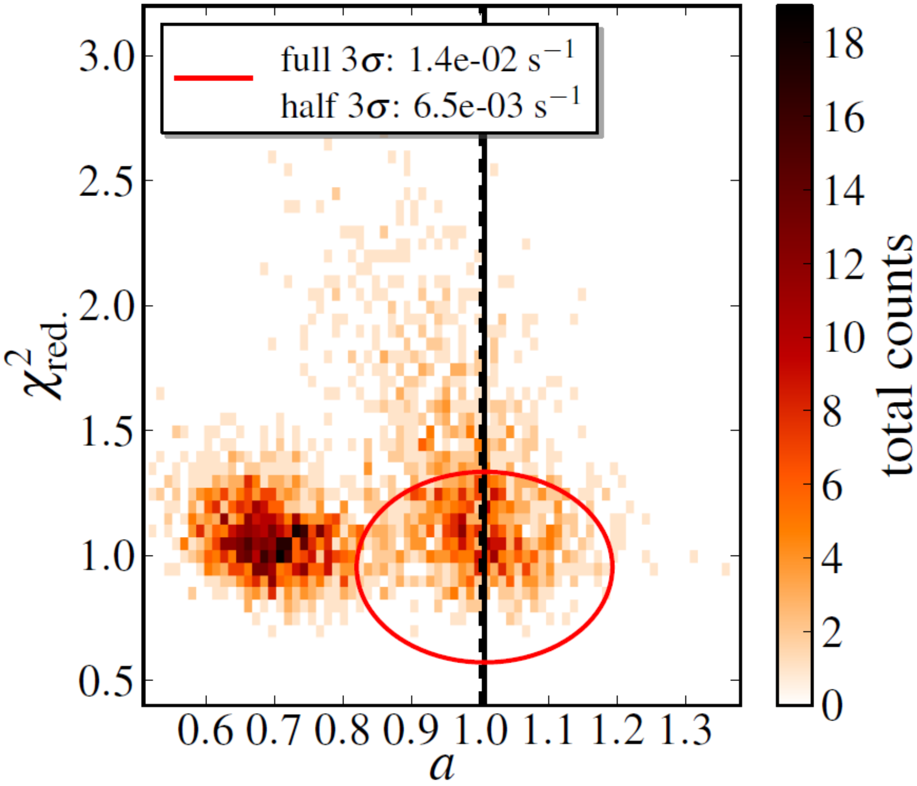




- The total background rate is about 0.01 Hz, but the rate of photon-like events is only (0.00010±0.00002) Hz.
- Is this the “ultimate noise limit” of the ALPS TES?

# More selected TES results

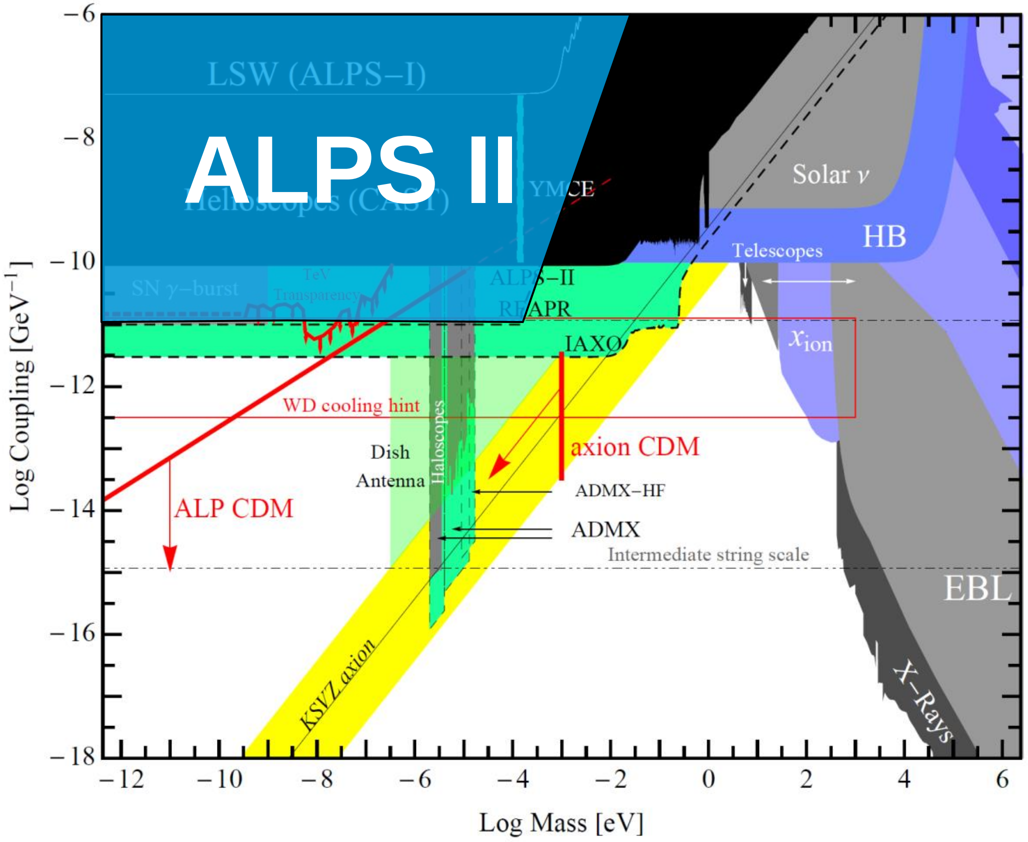
(Thesis of J. Dreyling Eschweiler, paper submitted to the *Journal of Modern Optics*)

- When the TES is coupled via an optical fiber to a dark room-temperature environment, background 1064 nm “photons” are registered at a rate of (0.0086±0.0011) Hz.
(using a set-up with an efficiency of 23%).
- Most likely this is caused by a pile up of black-body photons with longer wavelengths.



# ALPS II sensitivity

- Well beyond current limits.
- Less sensitive than IAXO



# ALPS II sensitivity

- Well beyond current limits.
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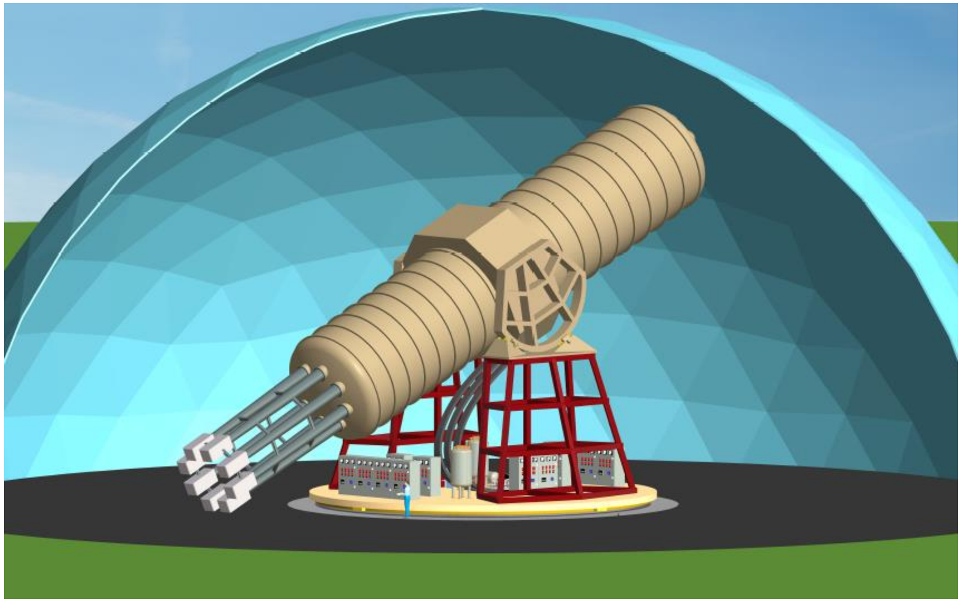

The proposed helioscope
**I**nternational **AX**ion **O**bservatory

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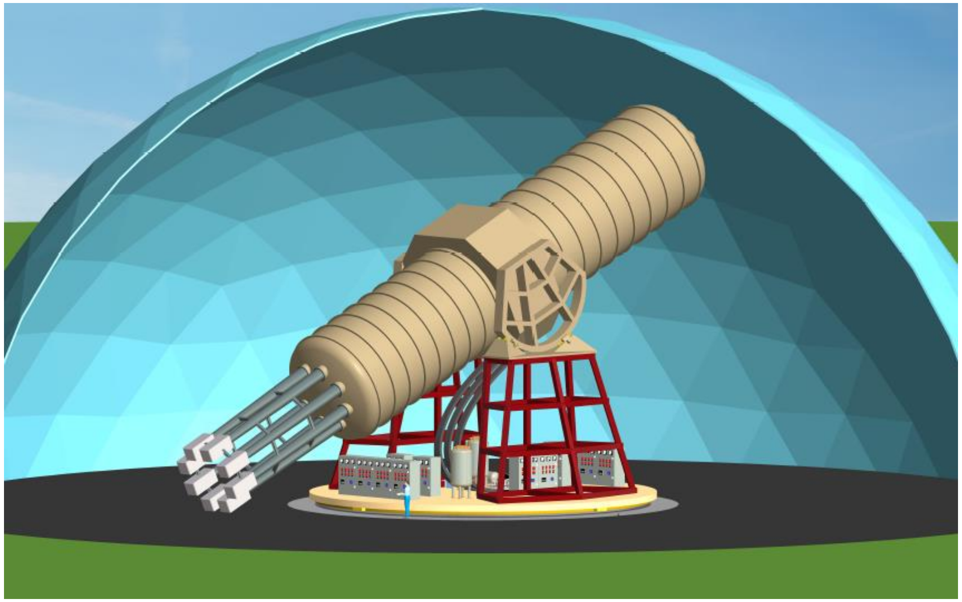
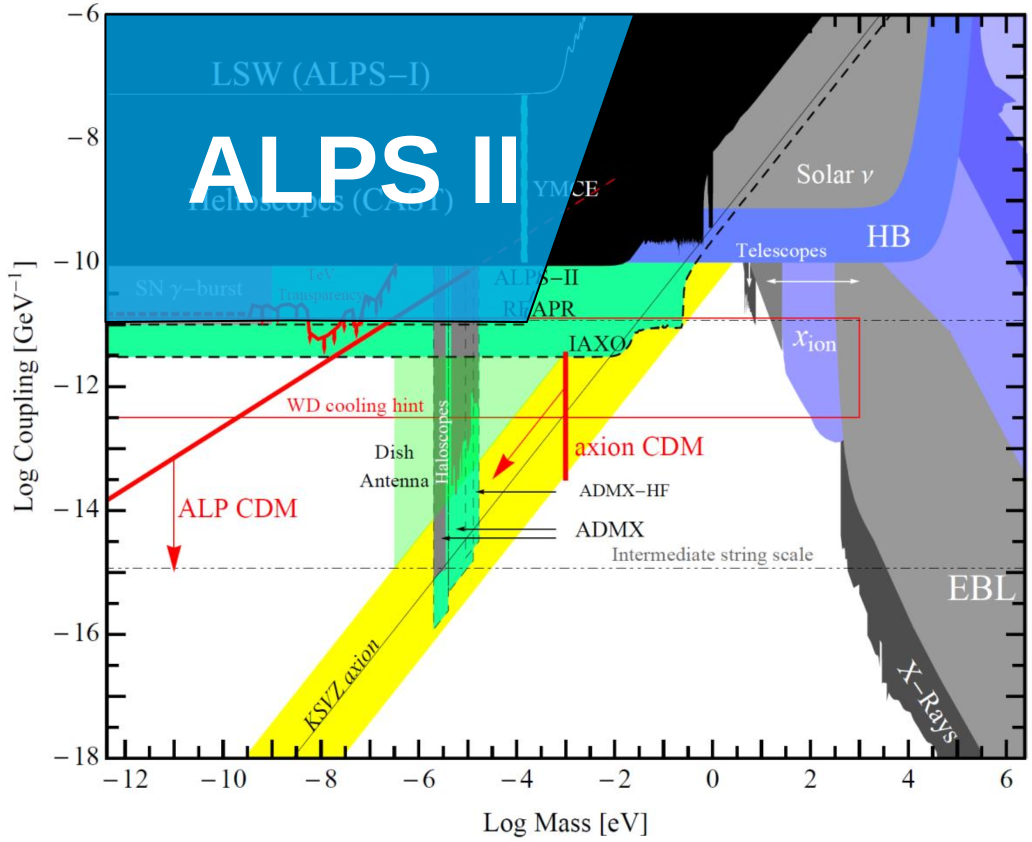


The proposed helioscope
**I**nternational **AX**ion **O**bservatory

SEE TALK BY ESTHER FERRER RIBAS

# ALPS II sensitivity

- Well beyond current limits.
- Less sensitive than IAXO (but much cheaper).
- Aim for data taking in 2018, likely before IAXO.
- QCD axions not in reach.
- Able to probe hints from astrophysics.



# Outline

- Why should one look for WISPs
- Indications for WISPs
- Searches
- Photons-through-a-wall
- **Summary**

# Summary

- Astrophysics might hint at the existence of axion-like particles.
  - Especially high energy cosmic photons from extragalactic sources could pin down a clear evidence for ALPs.
- ALPS II could search for these axion-like particles and other WISPs.
  - We aim for detecting one infrared photon within an hour.
- A detection of WISPs at ALPS II
  - would give insight into elementary physics at the $10^{10}$ GeV scale,
  - could be crucial to understand Dark Matter,
  - might point to an understanding of Dark Energy and
  - would provide a strong boost for solar physics with IAXO.
- Looking for WISPs

  in the lab, from the sun and as components of the dark matter halo

  nicely complements experiments at the energy frontier and other accelerator based efforts.

# Don’t put all eggs into one basket!

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annalen der physik

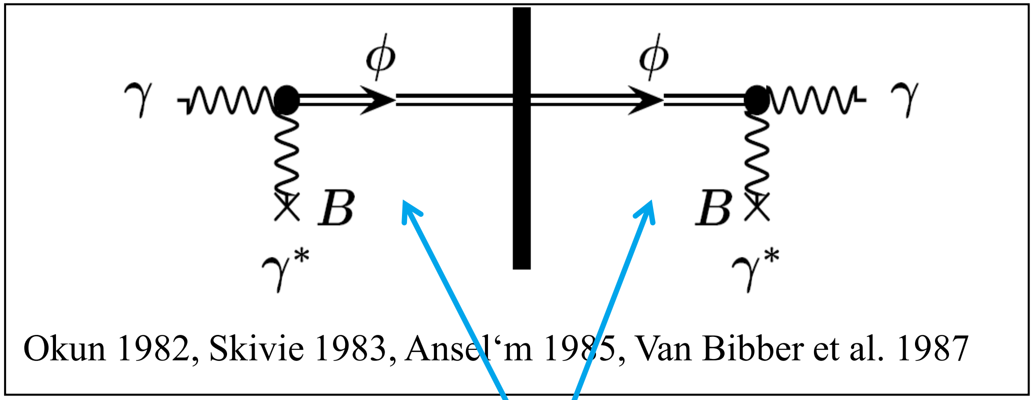
**The quest for axions and other new light particles**

*K. Baker[1], G. Cantatore[2], S. A. Cetin[3], M. Davenport[4], K. Desch[5], B. Döbrich[6,*], H. Gies[7], I. Irastorza[8], J. Jaeckel[9], A. Lindner[6], T. Papaevangelou[10], M. Pivovaroff[11], G. Raffelt[12], J. Redondo[12], A. Ringwald[6], Y. Semertzidis[13], A. Siemko[4], M. Sulc[13], A. Upadhye[14], and K. Zioutas[15]*

# Additional slides

# Basics of WISP experiments (II)

- Basic idea: due to their very weak interaction WISPs may traverse any wall opaque to Standard Model constituents (except ν and gravitons).
  - WISP could transfer energy out of a shielded environment
  - WISP could convert back into detectable photons behind a shielding.
- “Light-shining-through-a-wall” (LSW)




Real WISPs are produced!

# Basics of WISP experiments (III)

- Basic idea: due to their very weak interaction WISPs may traverse any wall opaque to Standard Model constituents (except ν and gravitons).
  - WISP could transfer energy out of a shielded environment
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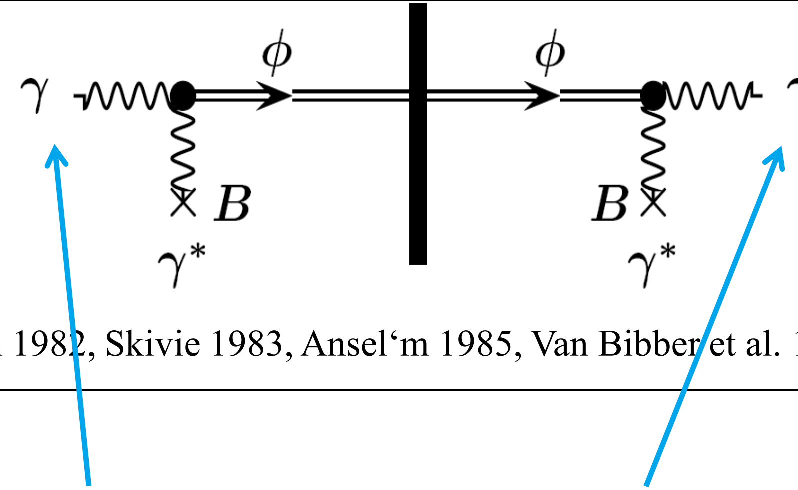
- “Light-shining-through-a-wall” (LSW)



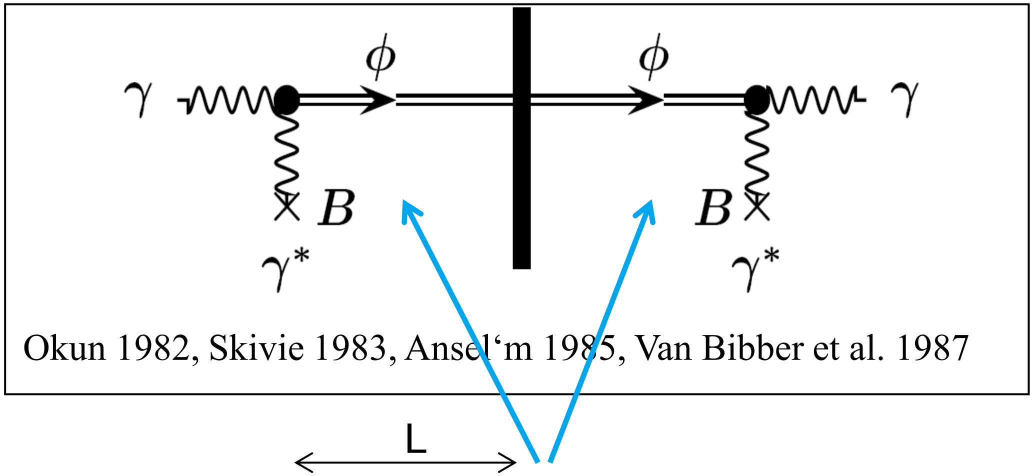

Okun 1982, Skivie 1983, Ansel‘m 1985, Van Bibber et al. 1987

The primary and the regenerated photons have exactly the same properties (energy, polarization).

# Basics of WISP experiments (IV)

- Basic idea: due to their very weak interaction WISPs may traverse any wall opaque to Standard Model constituents (except ν and gravitons).
  - WISP could transfer energy out of a shielded environment
  - WISP could convert back into detectable photons behind a shielding.

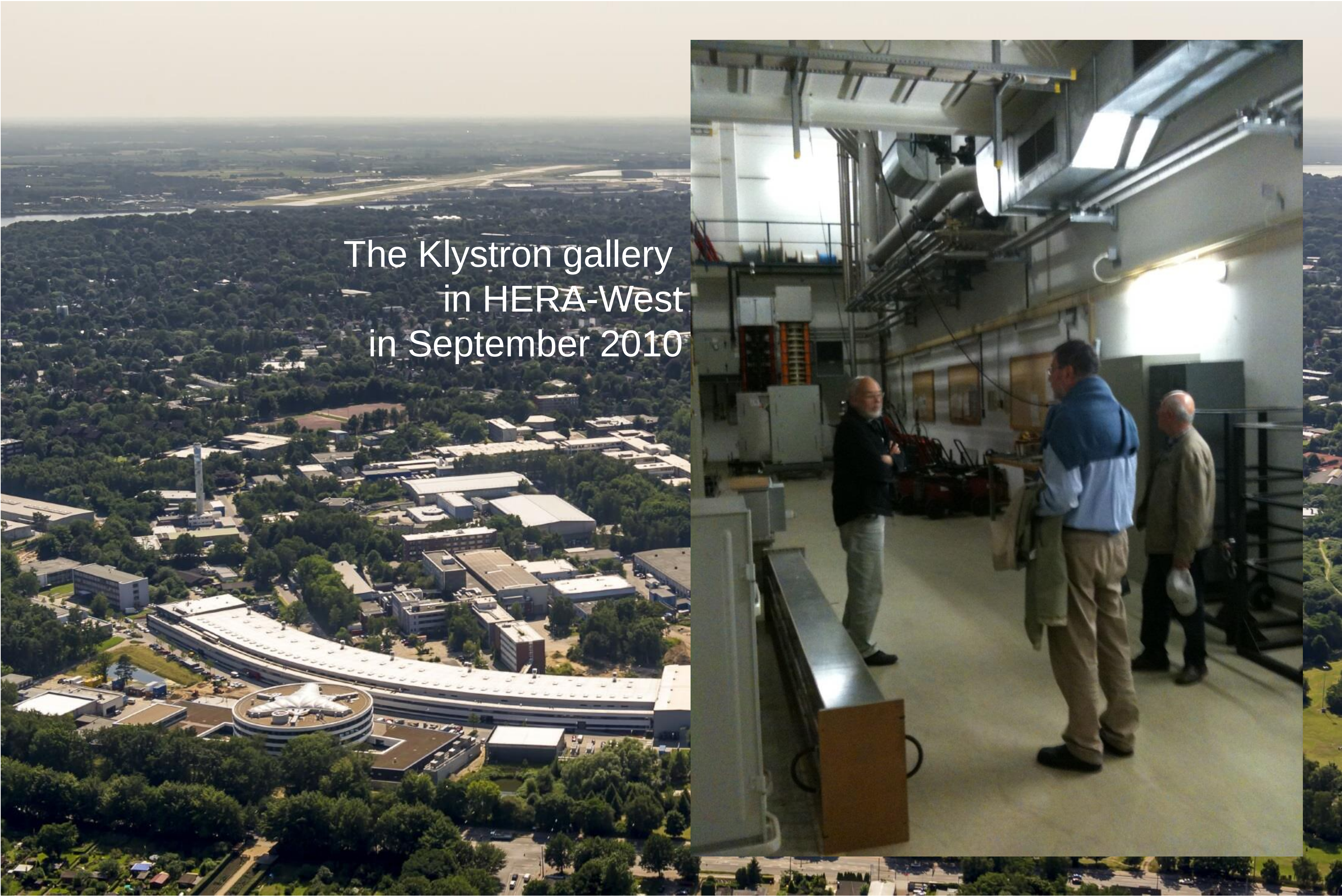
## "Light-shining-through-a-wall" (LSW)




Coherent production and regeneration: $P_{\gamma\rightarrow\Phi} \propto (B\cdot L)^2$

# ALPS IIa in HERA-WEST

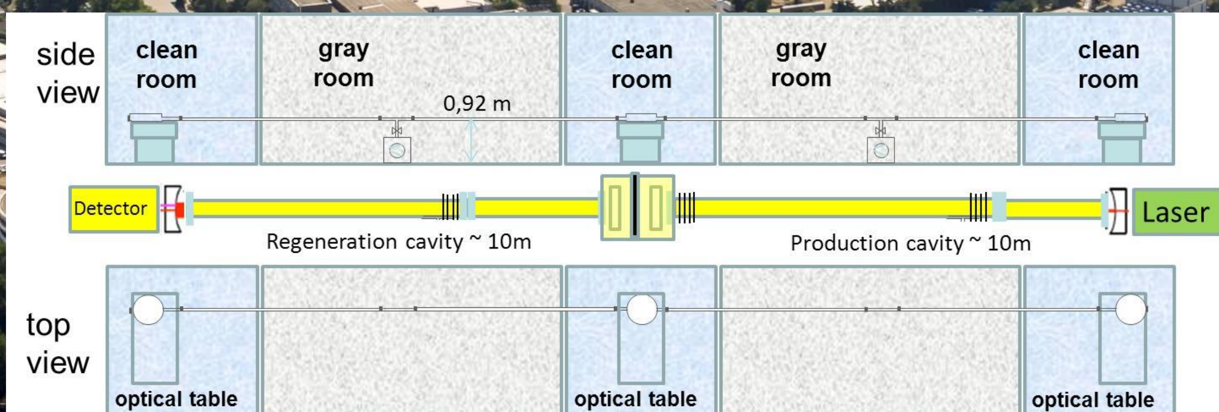
# ALPS IIa in HERA-WEST



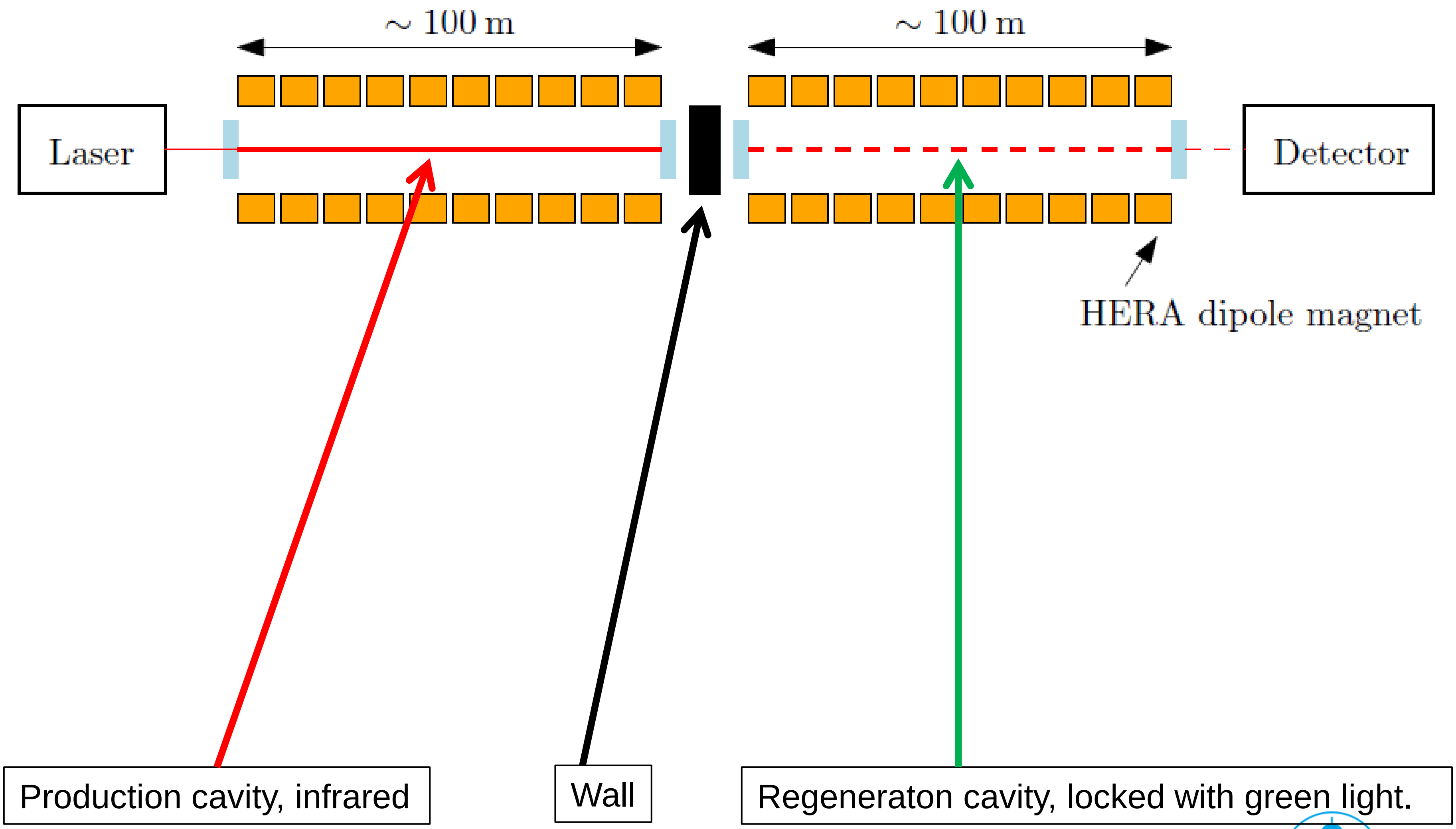
The Klystron gallery
in HERA-West
in September 2010

# ALPS IIa in HERA-WEST

Since 2012: the ALPS IIa laboratory in HERA-West



# ALPS II essentials: laser & optics



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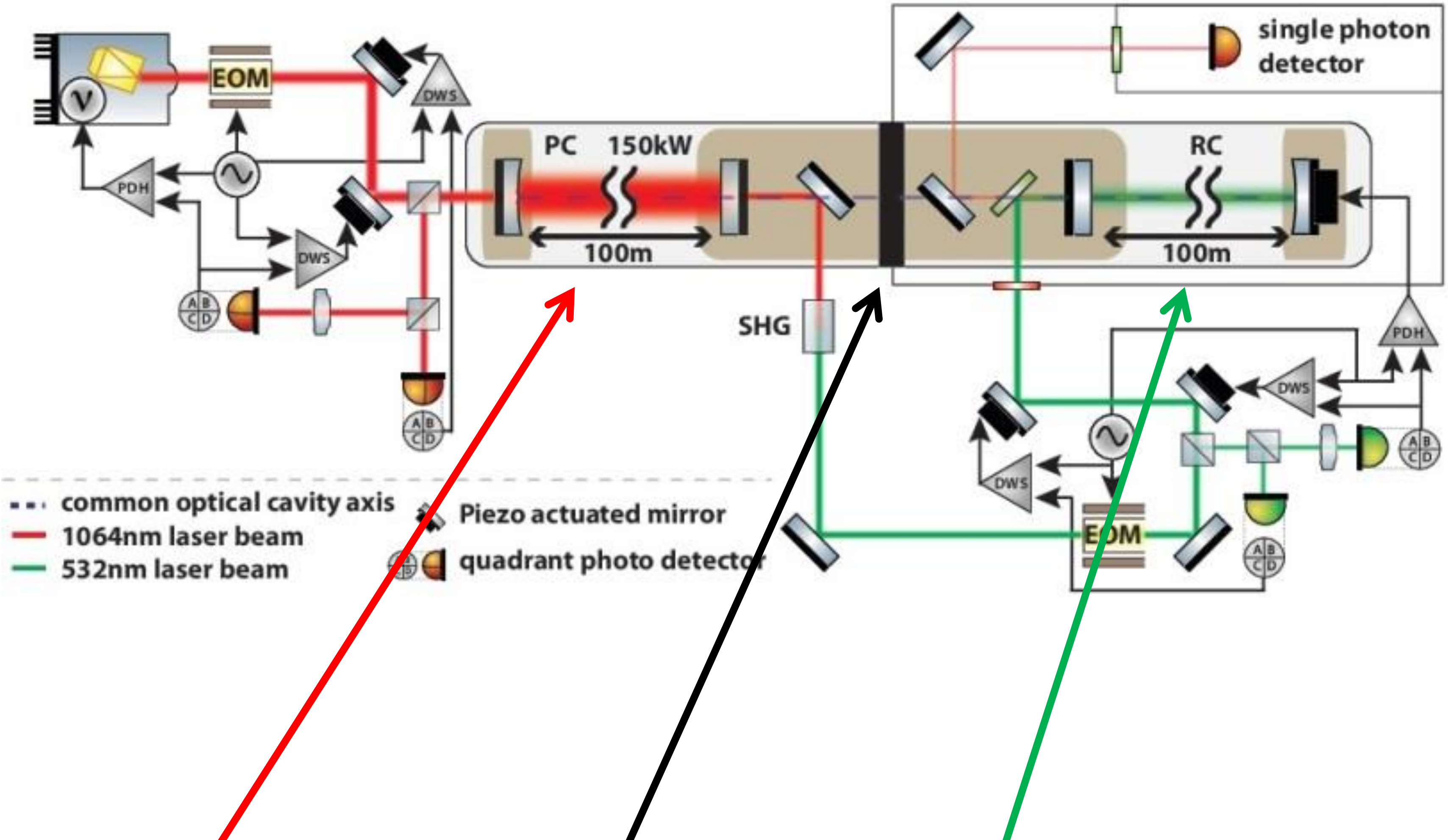
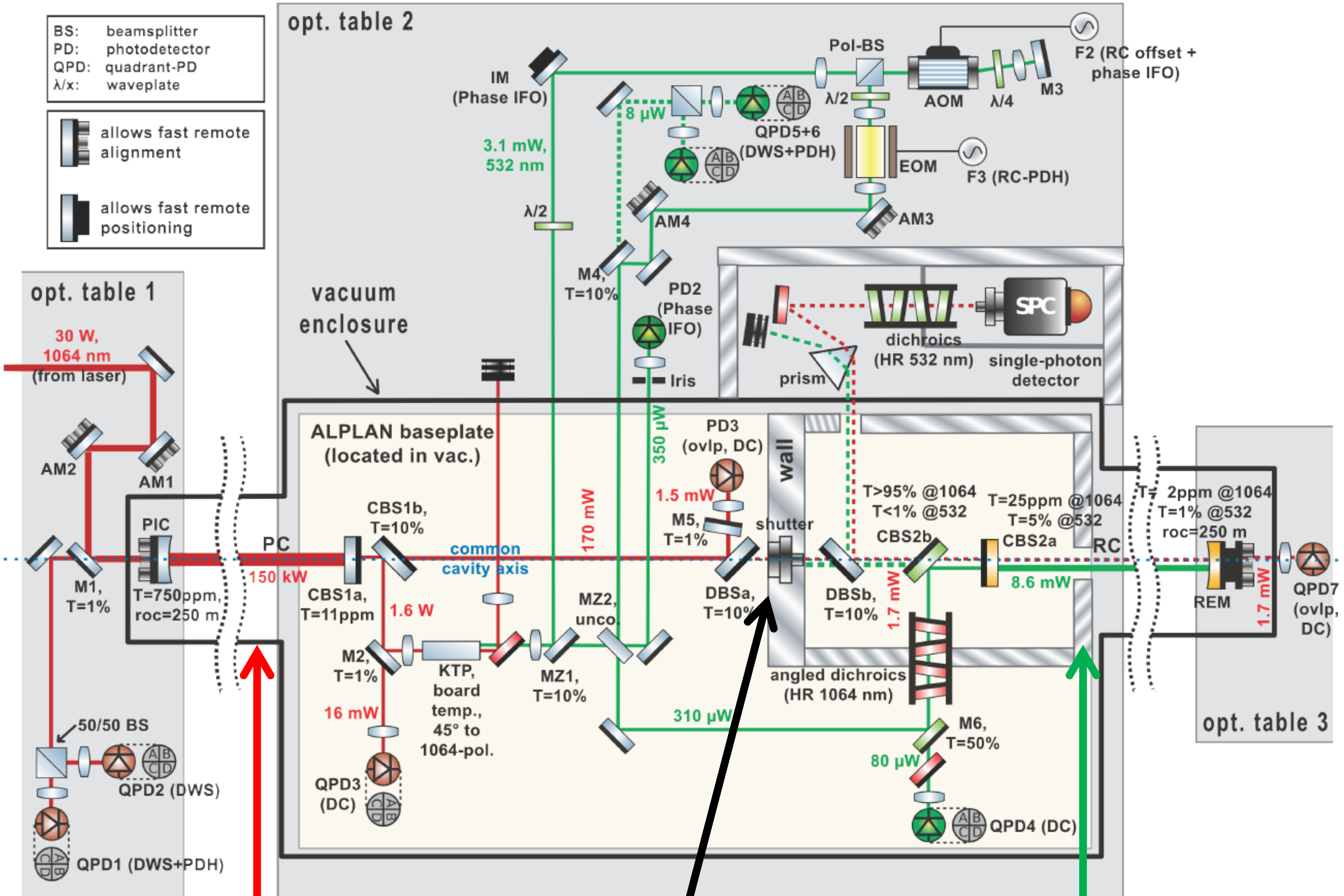



Production cavity, infrared

Wall

Regeneraton cavity, locked with green light.

# ALPS II essentials: laser & optics



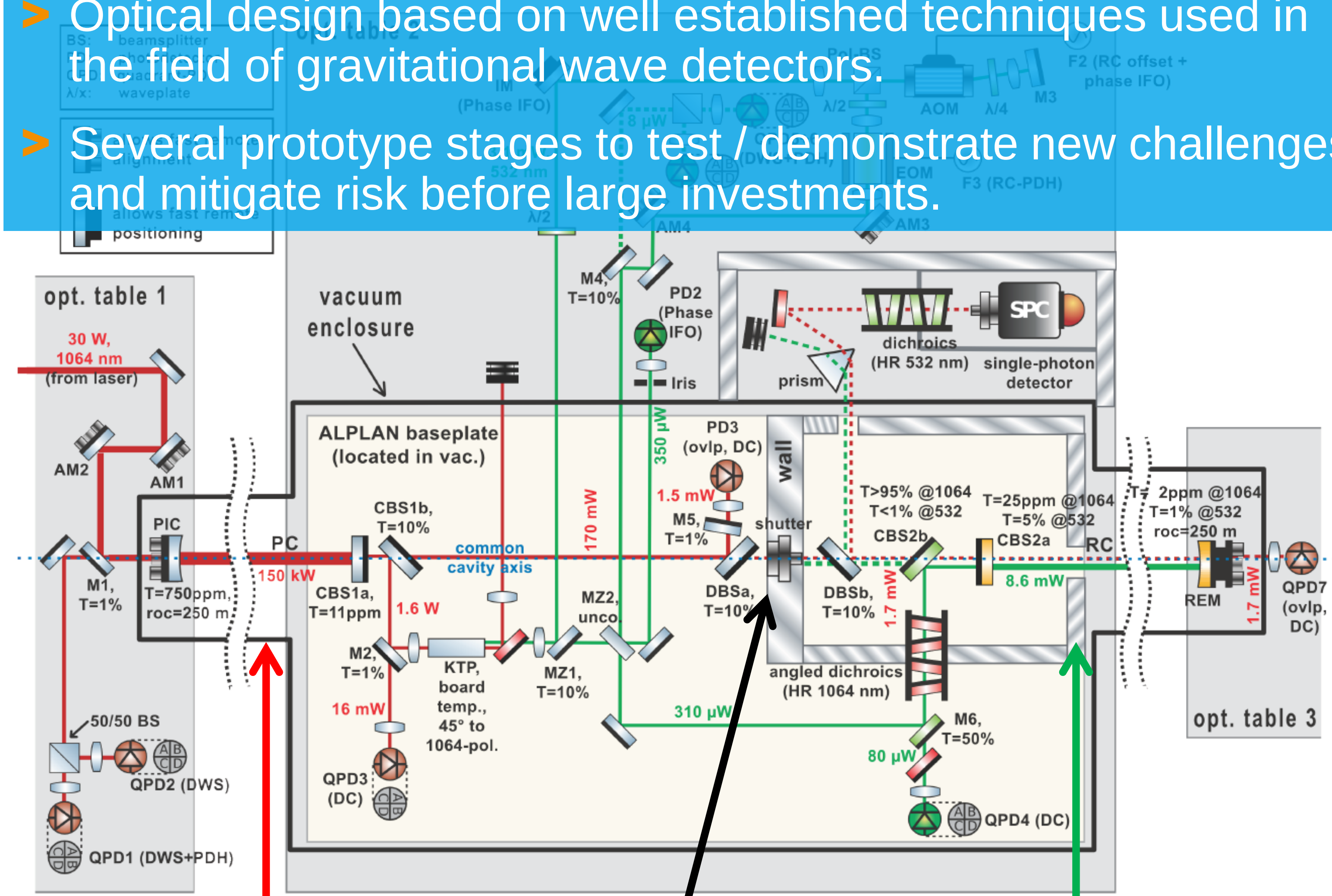

Production cavity, infrared

Wall

Regeneraton cavity, locked with green light.

# ALPS II essentials: laser & optics

- Optical design based on well established techniques used in the field of gravitational wave detectors.
- Several prototype stages to test / demonstrate new challenges and mitigate risk before large investments.

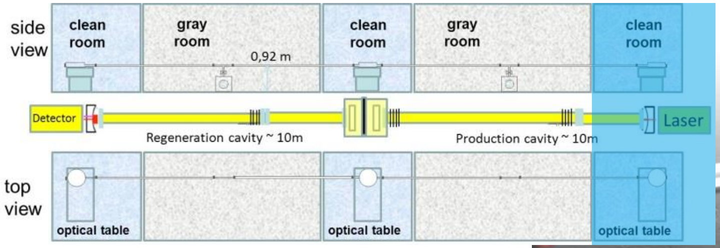


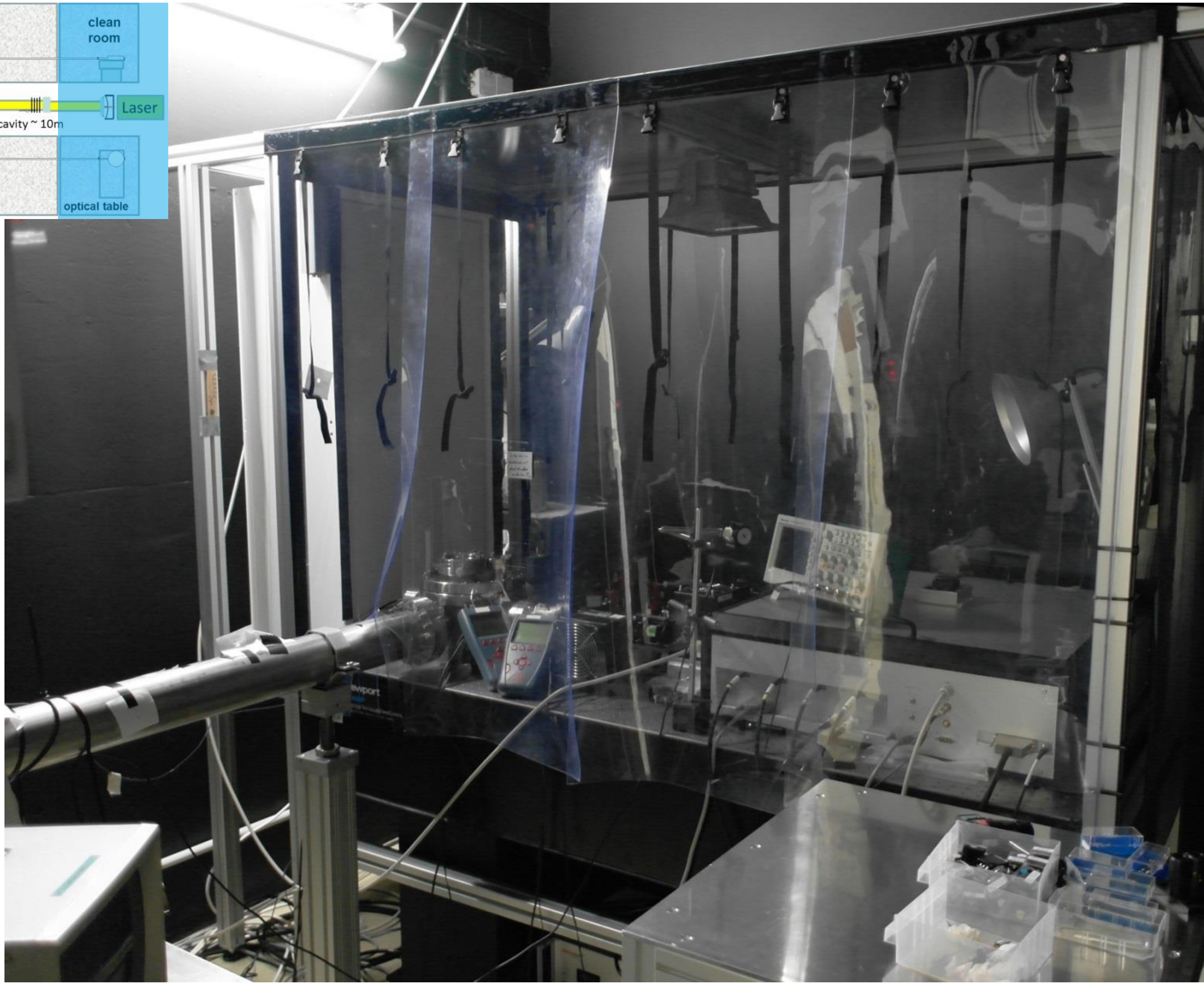

Production cavity, infrared

Wall

Regeneraton cavity, locked with green light.

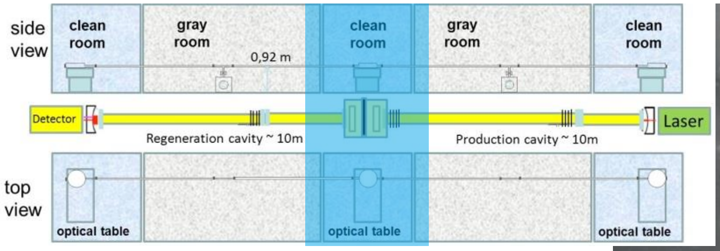
# The photon source

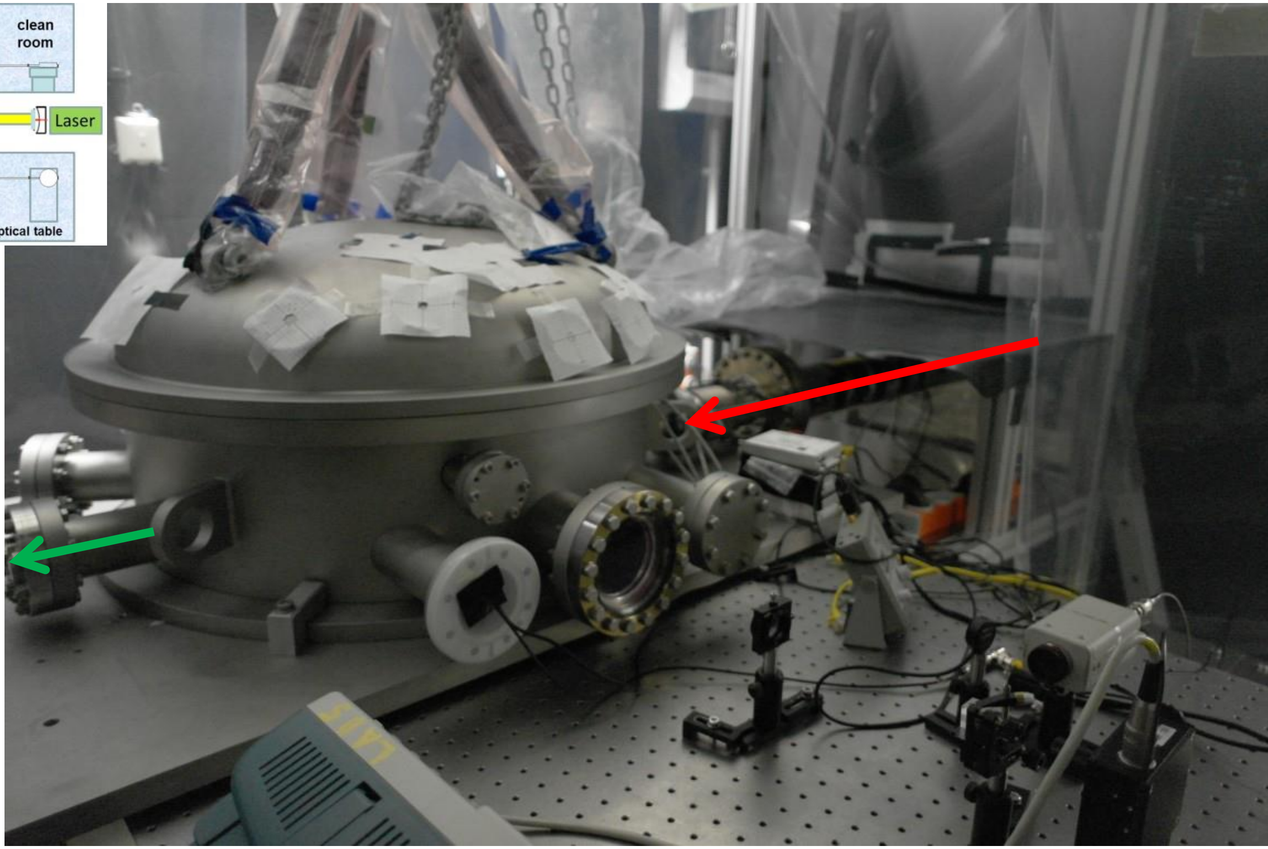


The laser has been developed for LIGO:
35 W, 1064 nm, $M^2$<1.1
based on
2 W NPRO by
Innolight/Mephisto
(Nd:YAG (neodymium-doped yttrium aluminium garnet)

# The central optics



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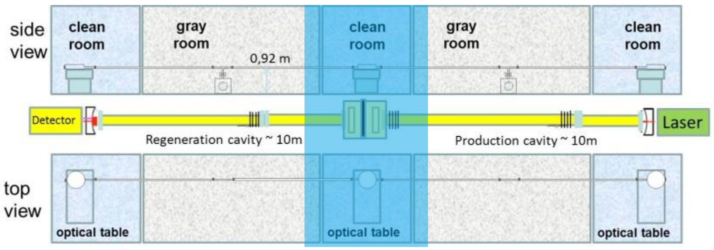


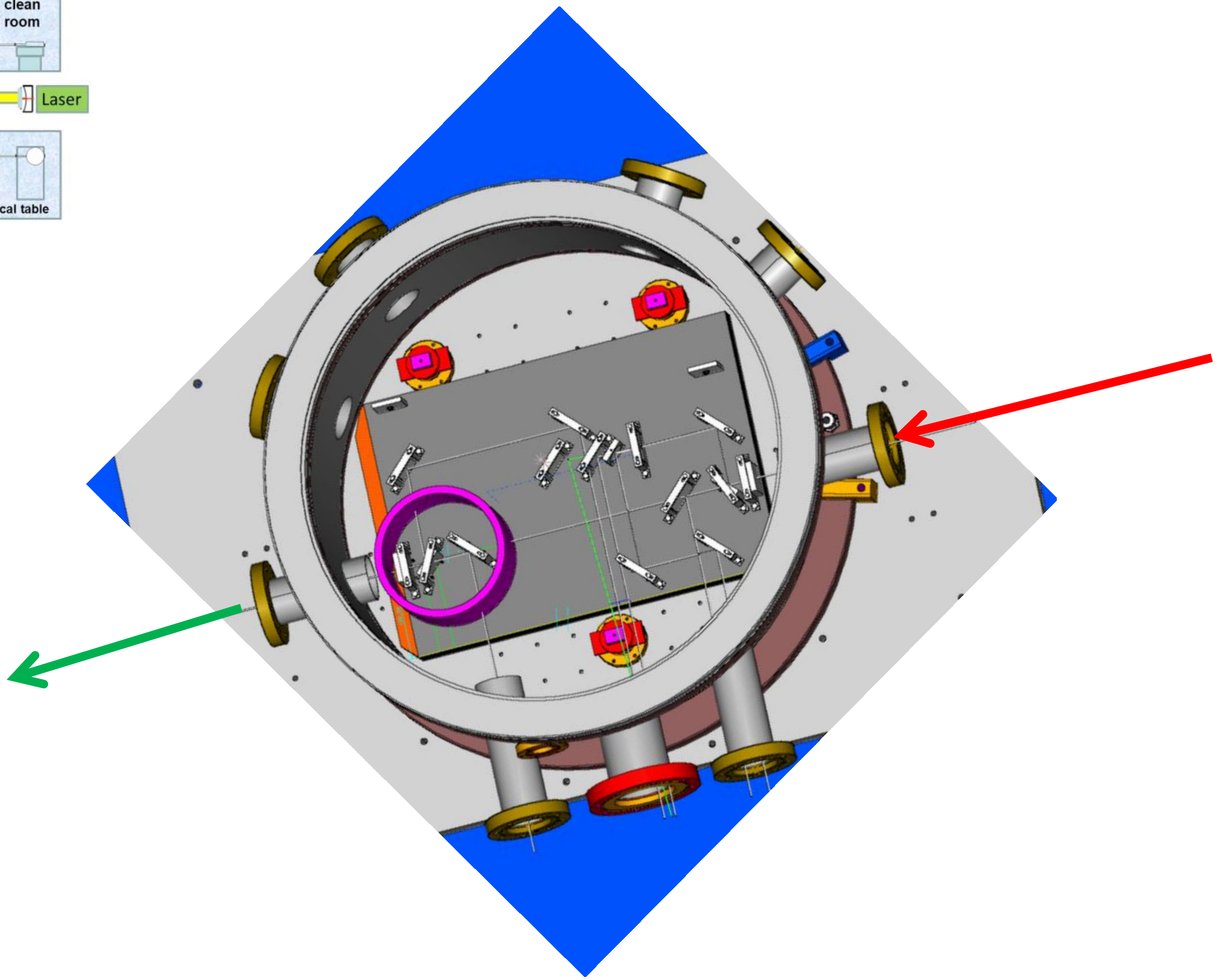

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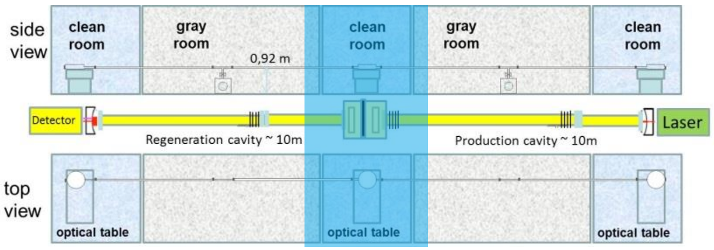
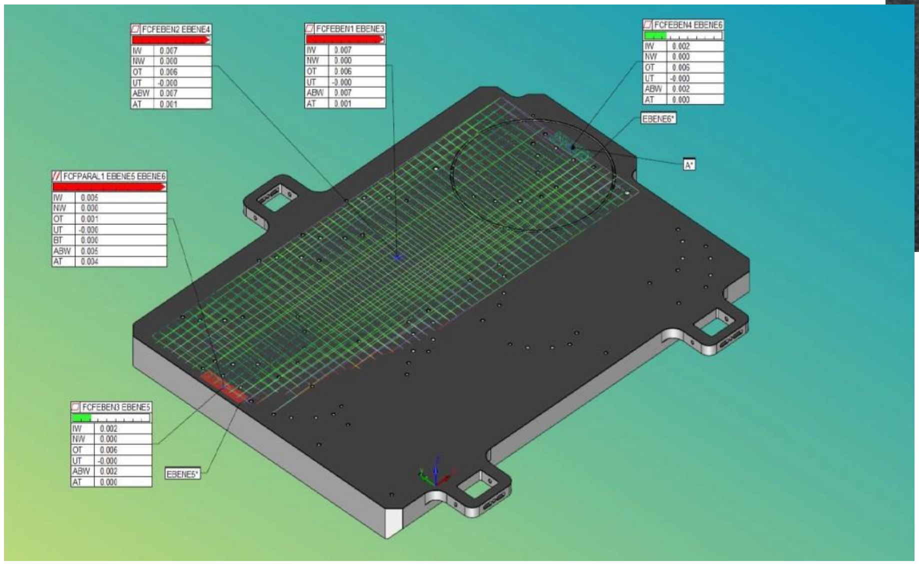
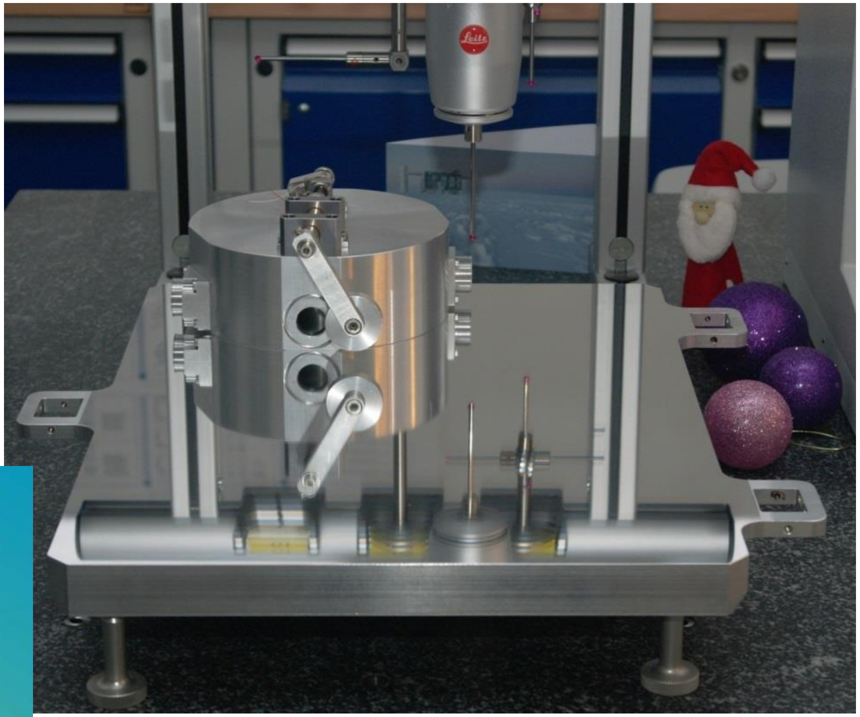




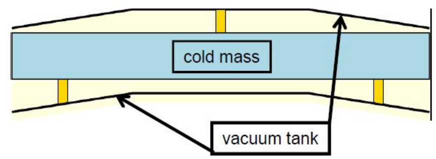
Thanks to Fred Knof from ZMQS!

# ALPS II magnets

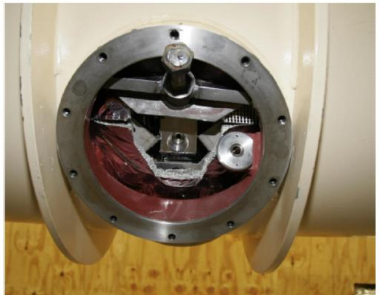
- The beam tube (cold mass) of the HERA dipoles has to be straightened
  to increase the aperture from 35 to at least 50mm.
- This can be done with a cheap “brute force” method.

Inexpensive method to increase the aperture of the vacuum pipe in the HERA dipole

Force ends and middle of cold mass towards the center with simple deformation tools

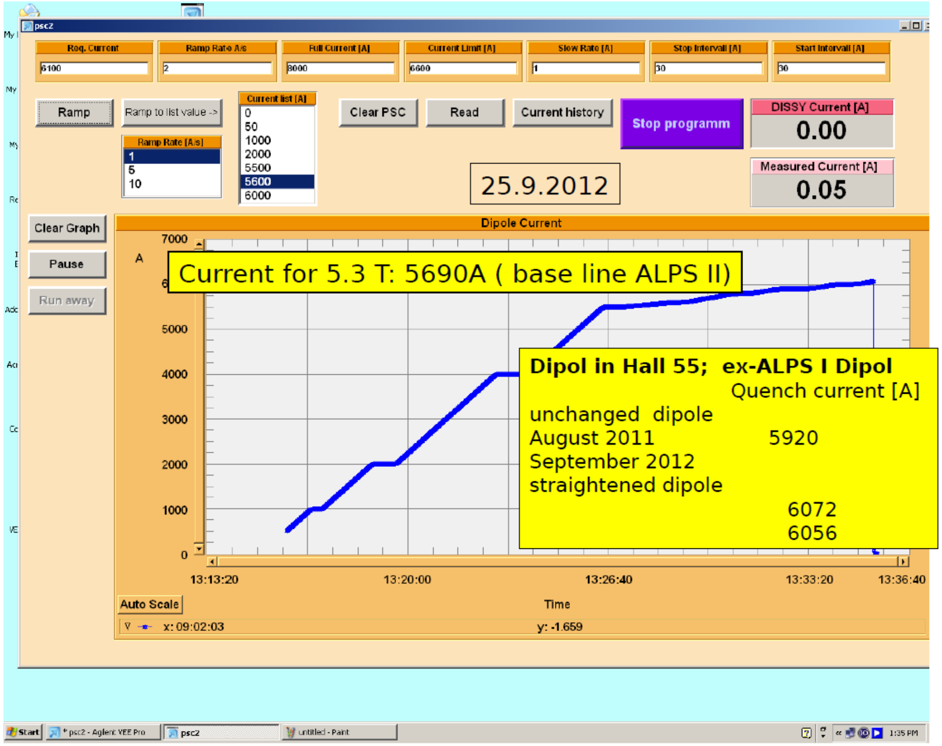



HERA dipole in Hall 1 received from PR



# ALPS II magnets

- The beam tube (cold mass) of the HERA dipoles has to be straightened
  to increase the aperture from 35 to at least 50mm.
- This can be done with a cheap “brute force” method.
- Already the first test in 2012 was successful.
- The straightening method was refined and tested in 2014 again.




- Test of a second HERA dipole is moving forward (if capacities of infrastructure groups allow).

# Beyond ALPS II

- Rough estimation with some crucial parameters:

| 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 | $3.5\cdot10^{21}$ | 2.3 | 5.0 | 4.4 | 22 | 1 | 0.0003 | 0.001 |
| ALPS II | $1\cdot10^{24}$ | 1.2 | 5.3 | 106 | 468 | 40,000 | 1 | 0.0002 |
| "ALPS III" | $3\cdot10^{25}$ | 1.2 | 13 | 400 | 5200 | 100,000 | 27 | 0.0001 |
| | | | | | | | | |
| European XFEL | $< 10^{18}$ | $1\cdot10^{4}$ | 5.3 | 106 | 562 | 1 | 0.001 | 0.01 |
| | | | | | | | | |
| PW laser | $10^{20}$ 1/pulse | 2.3 | $10^{6}$ | $10^{-5}$ | 10 | 1 | 0.0003 | 0.5 |



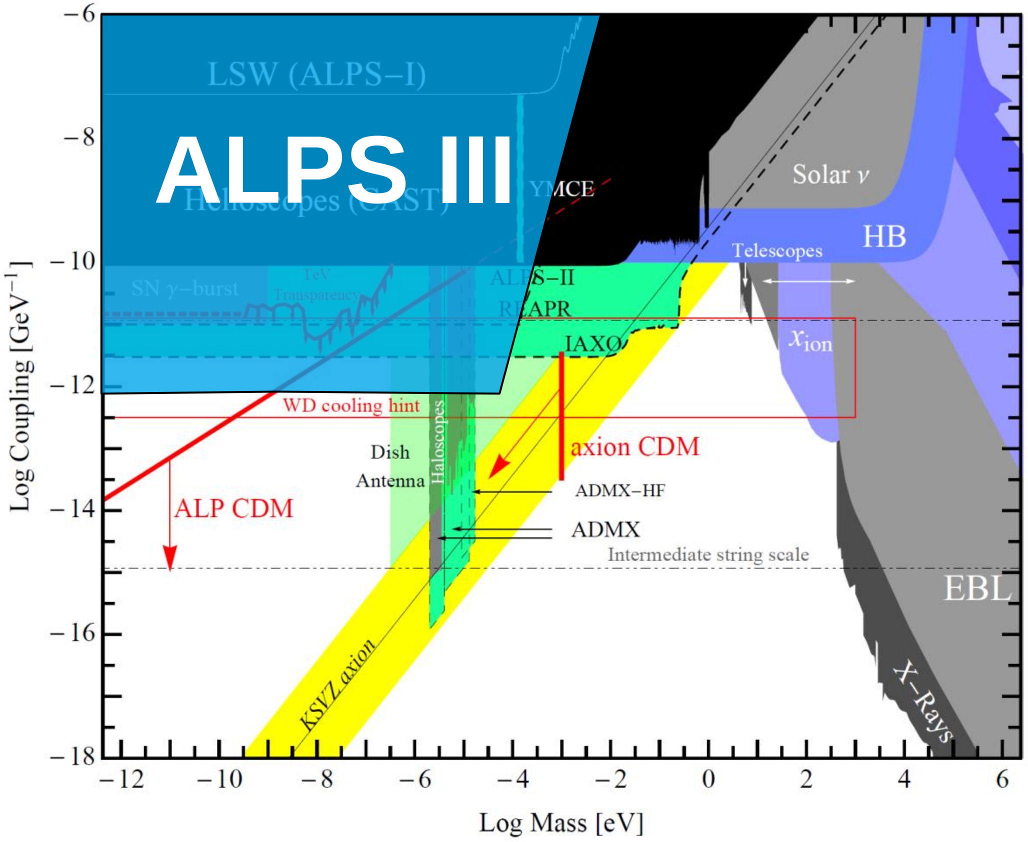
DESY

# “ALPS III” sensitivity

- With a multi - 10 M€ project one could even probe well beyond the IAXO reach.

However:

- It is to be shown first that ALPS II can be realized.
- Magnets as being developed for an LHC energy upgrade are essential.




- The physics case cannot be forecasted at present (beyond probing uncharted territory).

# WISP physics is fascinating!

Spektrum der Wissenschaft,
Juni 2014


TITELTHEMA: JENSEITS DES STANDARDMODELLS

## Ultraleichten Teilchen auf der Spur

Bisherige Ansätze bei der Suche nach neuen Teilchen, vor allem den Bestandteilen der Dunklen Materie, blieben bislang erfolglos. Physiker setzen daher auf unkonventionelle Strategien. Mit auf den ersten Blick erstaunlich einfach wirkenden Experimenten wollen sie ultraleichte Axionen und deren Verwandte aufspüren.

Von Joerg Jaeckel, Axel Lindner und Andreas Ringwald

Im Juli 2012 eroberten die Physiker die Schlagzeilen. Am CERN bei Genf, genauer am Teilchenbeschleuniger LHC

besonders schwere Teilchen nachweisen kann. Sogar über den Bau noch größerer Maschinen wird nun nachgedacht.
…seits verdeckt dieser Erfolg die Tatsache, dass der …weitere mit ihm verbundene Hoffnung bislang …lt hat: nämlich auch Teilchen der so genannten …aterie nachzuweisen. Möglicherweise sorgen erst …n Energien, die der Beschleuniger ab 2015 errei… für den Durchbruch. Daneben lassen theoretische …imentelle Fortschritte aber auch die Suche in ent…tzter Richtung sehr viel versprechend erscheinen, …e nach extrem leichten Teilchen.
…vor der Entdeckung des Higgs war klar, dass das …odell die uns umgebende Materie auf einer fun…n Ebene und höchst präzise beschreibt. Bis heute …borexperiment eine signifikante Abweichung von …hersagen ergeben. Auch das Higgs selbst hat die…tischen Rahmen glänzend bestätigt. Trotzdem su…rscher nach Physik jenseits des Standardmodells; …erem deshalb, weil astronomische Beobachter in …ngenen Jahrzehnten zu dem überraschenden Be…mmen sind, dass sich nur 15 Prozent der Materie …s mit den üblichen Teilchen erklären lassen. Die …den 85 Prozent – und damit der Löwenanteil – ent…gen auf Dunkle Materie. Über die Teilchen, aus der …Substanz vermutlich zusammensetzt, wissen wir …ass sie allenfalls ein wenig mit Licht und anderen …s dem Standardmodell wechselwirken. Trotzdem …m aus dem Universum wegzudenken: Dank ihrer

### DIE AUTOREN

**Joerg Jaeckel** (links) ist Professor am Institut für Theoretische Physik der Universität Heidelberg und forscht über Physik jenseits des Standardmodells. Er beschäftigt sich mit ultraleichten Teilchen, aber auch mit LHC-Physik. **Axel Lindner** (Mitte) ist experimenteller Teilchenphysiker am Deutschen Elektronen-Synchrotron (DESY) in Hamburg und Sprecher des ALPS-Projekts. **Andreas Ringwald** ist ebenfalls Physiker am DESY. Er konzentriert sich auf theoretische Vorhersagen der Eigenschaften ultraleichter Teilchen sowie auf ihre Überprüfung in Laborexperimenten und hat in diesem Rahmen das ALPS-Projekt angestoßen.

36 SPEKTRUM DER WISSENSCHAFT · JUNI 2014