The ALPS-II experiment.

Unprecedented sensitivity for 'very light particles beyond the SM'

Babette Döbrich
Niccolò Cabeo School
Ferrara, May 23rd 2013

HELMHOLTZ GEMEINSCHAFT

DESY

Outline

- T/P: ALPS-II: Motivation, Goals and Tools Overview
- E: Laser and optics
- E: Magnet system
- E: Detection system
- More on helio- and haloscopes
- Closing words

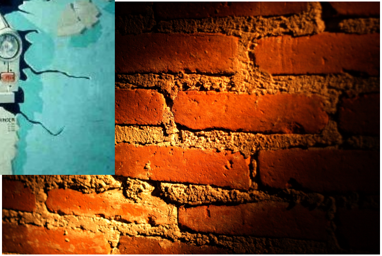
A propagandistic list of (astro-)particle questions

	rather massive particles?	low mass but very weakly coupled?
Fundamental (pseudo-) scalar particles?	(✓)	✗
Finetuning/Hierarchy?	✗	✗
What appears in UV-completions of the Standard Model?	✗	✗
Observational puzzles in astroparticle physics	?	✗
What is the nature Dark Matter/Dark Energy?	✗, ?	✗

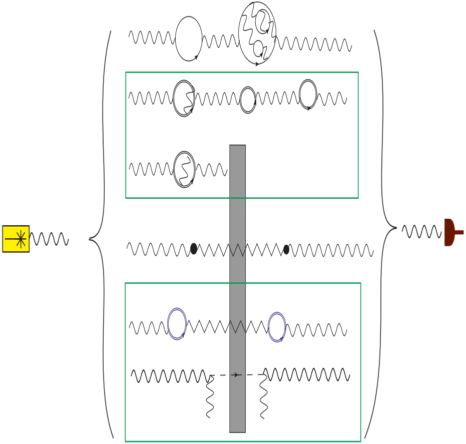
Rather massive particles: high energy $\rightarrow$ Accelerators, Direct Dark Matter WIMP detection

Low mass but very weakly coupled: Weakly Interacting Slim Particles $\rightarrow$ High intensity $\rightarrow$ laser photons, low background, precision, Light-shining-through-a-wall

Light-Shining-Through-a-wall?



The Light-shining-through-a-wall principle



> photon propagation ↔ QED

[nontrivial polarization → G. Zavattini's talk]

> shine laser on opaque barrier

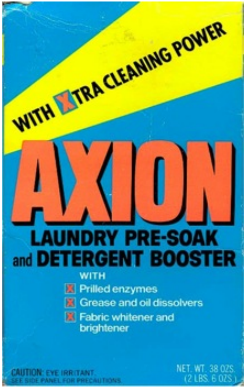
[theory: Sikivie '83, v. Bibber '87] [exps:BFRT, LIPPS, ALPS-I, OSQAR, GammeV]

> wall blocks all SM processes except neutrino (via W) and "graviton" (both negligible!)

> Beyond SM: WISPs (sub-eV) traverse wall (weak coupling), reconvert to γ

> some need B-field (spin!)

The Axion and ALPs - nucleus of WISP physics



- Axion = pseudo-scalar pseudo-GSB [Peccei/Quinn'77,Weinberg '78,Wilczek'78] $\leftrightarrow$ 'wash away' the strong CP problem ($d_n < 10^{-26}$ecm cf. E. Stephensons talk)

2002 Sirlin, Marciano

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Home | Programs | Prizes, Awards and Fellowships | Prizes | **J. J. Sakurai Prize for Theoretical Particle Physics**

J. J. Sakurai Prize for Theoretical Particle Physics

To recognize and encourage outstanding achievement in particle theory. The prize consists of $10,000, an allowance for travel to the meeting of the Society at which the prize is to be awarded, and a certificate citing the contributions made by the recipient. It will be presented annually.

Establishment & Support

This prize was endowed in 1984 as a memorial to and in recognition of the accomplishments of J. J. Sakurai by the family and friends of J. J. Sakurai.

Rules & Eligibility

Nominations are open to scientists of all nationalities regardless of the geographical site at which the work was done. The prize may be awarded to more than one person on a shared basis. The prize will normally be awarded for theoretical contributions made at an early stage of the recipients research career. Nominations are active for three years.

Nomination & Selection Process

This year's deadline has passed. Please check back soon for next year's nomination information and deadline.

2013 Selection Committee: James Wells, Chair; H. Murayama; K. Lane; J. Bagger; M Carena

2013 J.J. Sakurai Prize for Theoretical Particle Physics Recipient(s):
Helen Quinn
SLAC
Roberto Peccei
University of California, Los Angeles

Past Recipients:

2012: Bryan Webber
Guido Altarelli
Torbjorn Sjostrand

2011: Chris Quigg
Estia Eichten
Ian Hinchliffe
Kenneth Lane

2010: Carl R. Hagen
Francois Englert
Gerald S. Guralnik
Peter W. Higgs
Robert Brout
T.W.B. Kibble

2009: Davison E. Soper
John C. Collins

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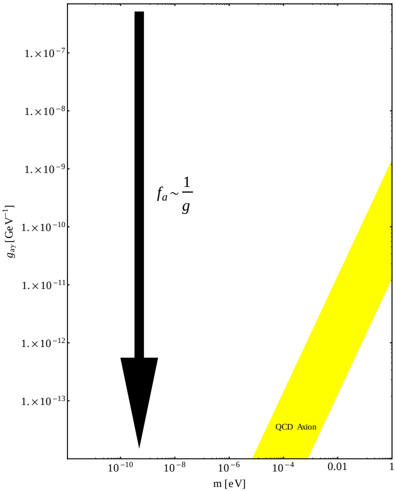

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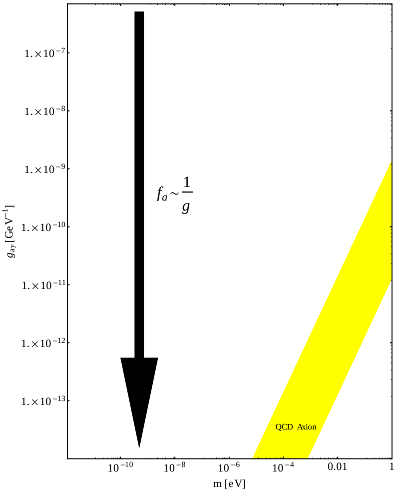

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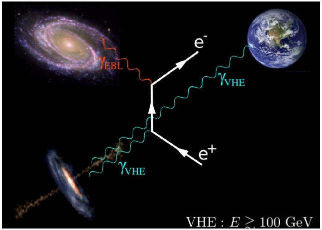

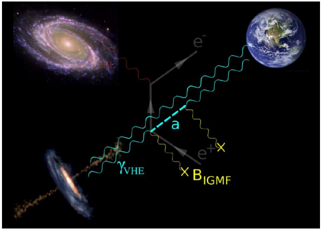

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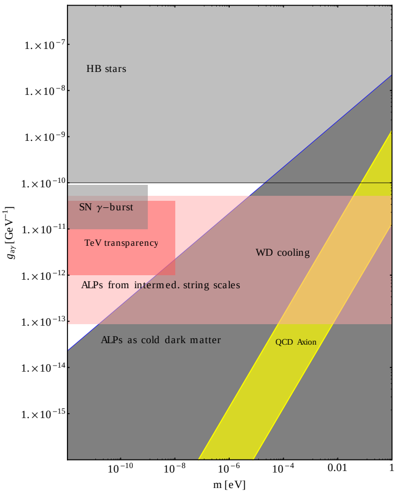

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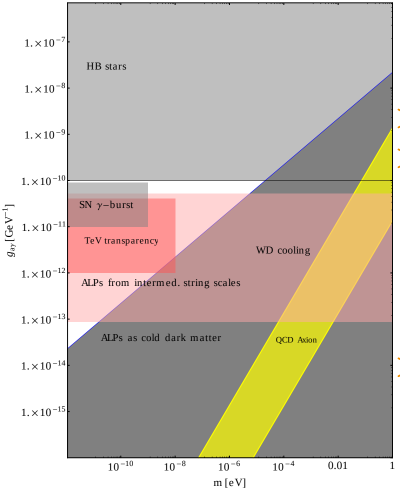

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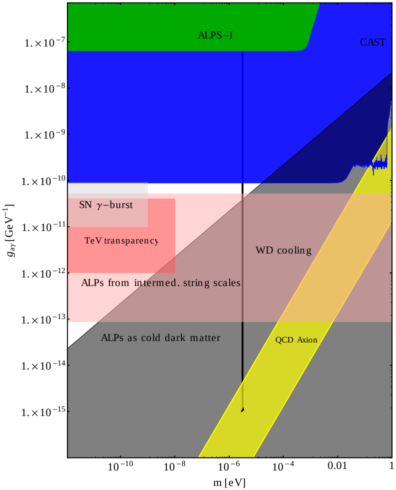

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- search with $\vec{B}$: $\mathcal{L}_{\text{int,PS}} \sim \phi F_{\mu\nu} \tilde{F}^{\mu\nu}$
  - solar (e.g. CAST@CERN)
  - Dark Matter (e.g. ADMX)
  - homemade (ALPS-I, ALPS-II)

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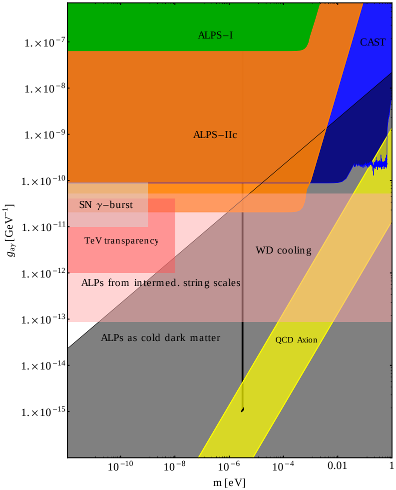

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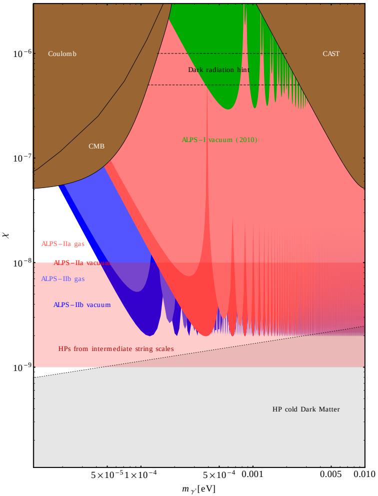
Further WISPs to be discovered with ALPS-II



- hidden (dark/heavy) photons from string & field-theory extensions cf. W. Marcianos talk at low mass
  $\mathcal{L} \sim \chi F_{\mu\nu} X^{\mu\nu} + m_{\tilde{\gamma}}^2/2 X_\mu X^\mu$
  - Dark Matter candidate & ~~possibly Dark Radiation [0804.4157]~~ however new solar constr' [1302.3884]
  - experimentally no need for B-fields, oscillation process
  - ALPS-I, ALPS-IIa, ALPS-IIb
  - if B-field applied, also sensitive to minicharged particles (fractionally charged hidden matter)
    $\mathcal{L} \sim \chi F_{\mu\nu} X^{\mu\nu} + e\bar{\psi} \not{A} \psi + e_{\mathrm{h}} \bar{h} \not{X} h$

Further WISPs to be discovered with ALPS-II

Shining Light on Modifications of Gravity

Philippe Brax,[1] Clare Burrage[2] and Anne-Christine Davis[3]

[1]Institut de Physique Théorique, CEA, IPhT, CNRS, URA2306, F-91191 Gif-sur-Yvette cédex, France
[2]School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, UK

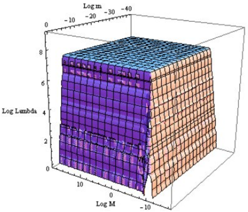


Figure 3. The constraint of the ALPS experiment on the m, M, Λ parameter space. All regions below the surface are excluded. The parameters are measured in units of GeV.

In Figure 3 the constraint of the ALPS experiment is shown in the three dimensional parameter space (m, M, Λ). We see that in almost all of the interesting range the constraint on Λ is that of the conformally coupled axion-like particle case $\Lambda \gtrsim 10^7$ GeV.

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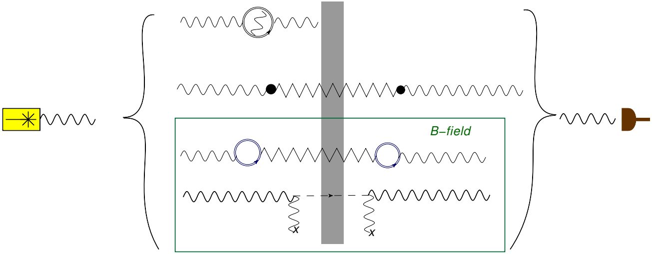
- scalar fields of massive gravity theories [1206.1809]

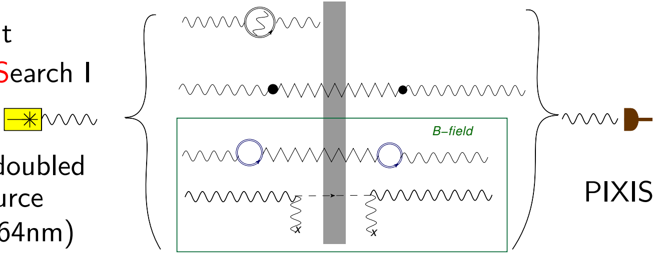
The LSW principle and technical upgrades



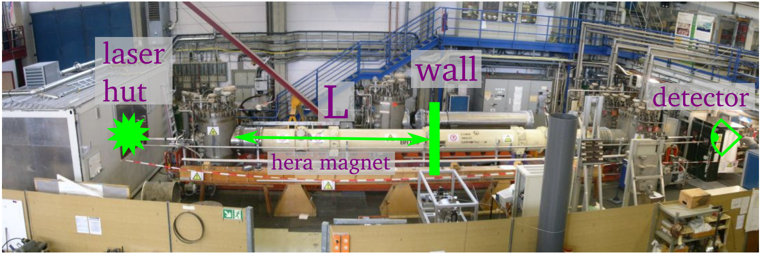
The LSW principle and technical upgrades

Any Light Particle Search I

frequency doubled infrared source ('35W', 1064nm)



PIXIS CCD



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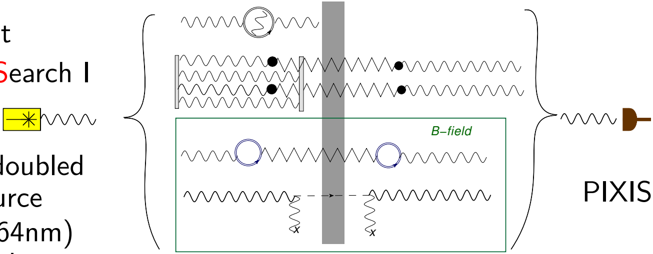

frequency doubled infrared source ('35W', 1064nm) +Resonator!

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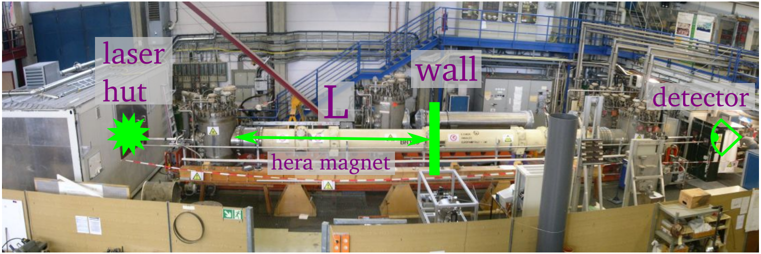
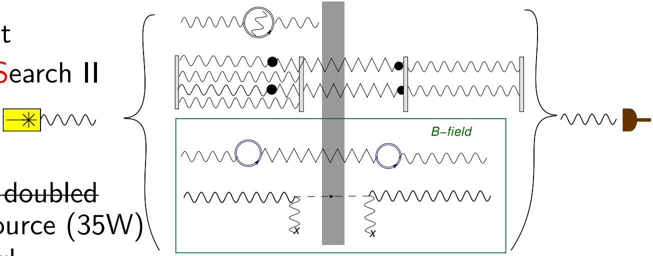


DESY

The LSW principle and technical upgrades

Any Light
Particle Search II



~~frequency doubled~~
infrared source (35W)
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Possible upgrades

> (Even) More photons → enhanced probability

Technical realization

> *coupled* cavities on both sides of the wall

The LSW principle and technical upgrades

Any Light

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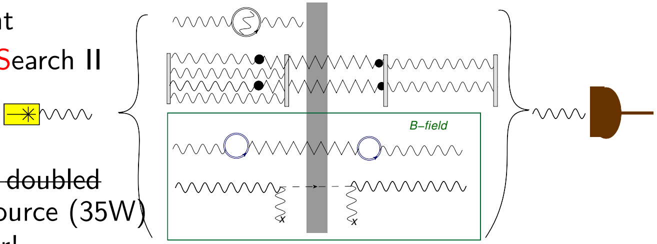

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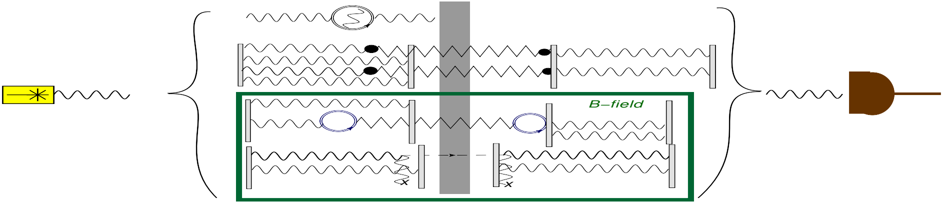
The LSW principle and technical upgrades



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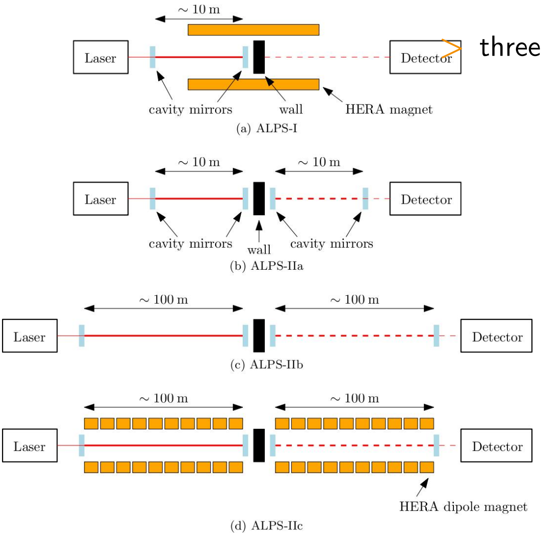
- HERA! (92-07) enhance length → tunnel

Status & Organizational matters



> three stages ALPS-II a,b,c

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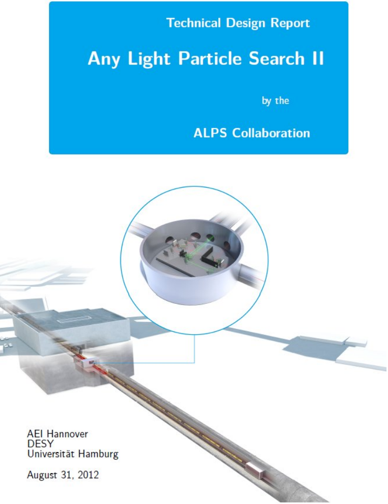

- three stages ALPS-II a,b,c
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  - 4 (part-time) scientists, 3 retired, 2 postdocs, 4 PhD students
  - tentative expansion!

Albert-Einstein-Institut
Hannover

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- $\lesssim$ 2M for 5 yr thereof $\approx$ 1M already spent

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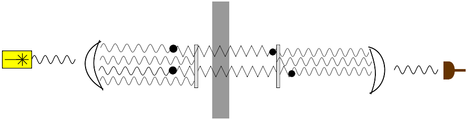
Resonant regeneration



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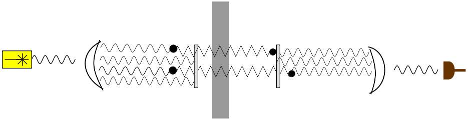
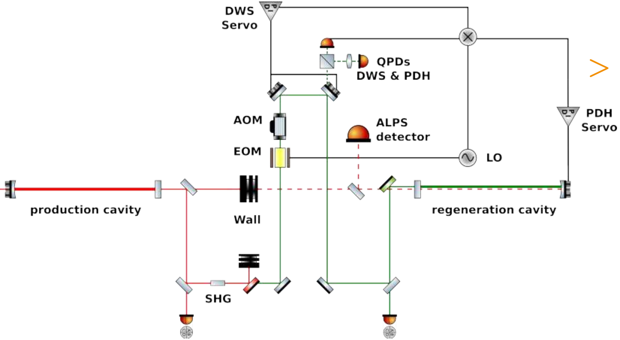
  - "photon selfinterference" experiment: arXiv:1101.4089, theory: Hoogeveen/Ziegenhagen
  - momentum conservation $\rightarrow$ frequency-lock (PDH) the two cavities

Resonant regeneration





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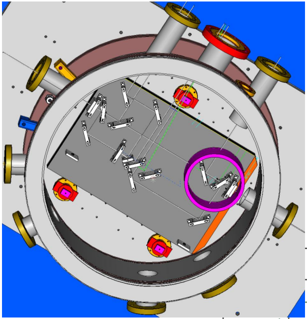

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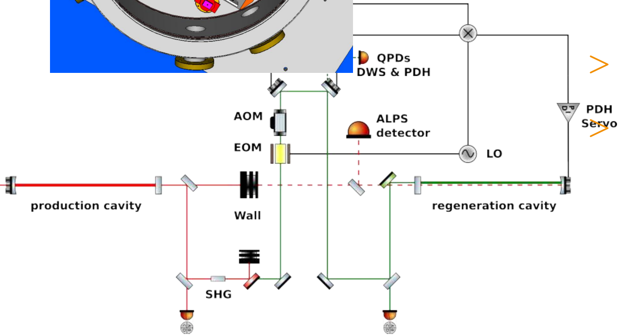

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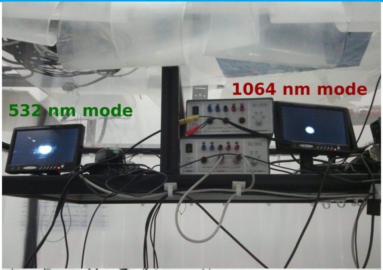

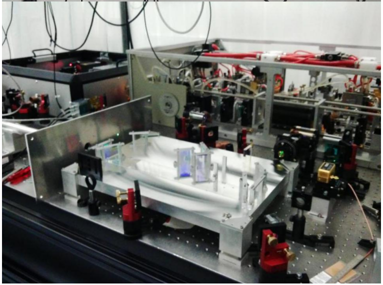

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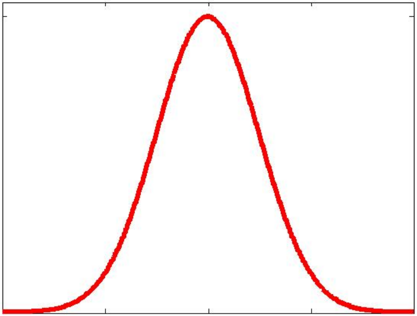
- experimental status
  - 1m test-proof-of-principle in Hannover (locking ok, PB?)

Aperture constraints



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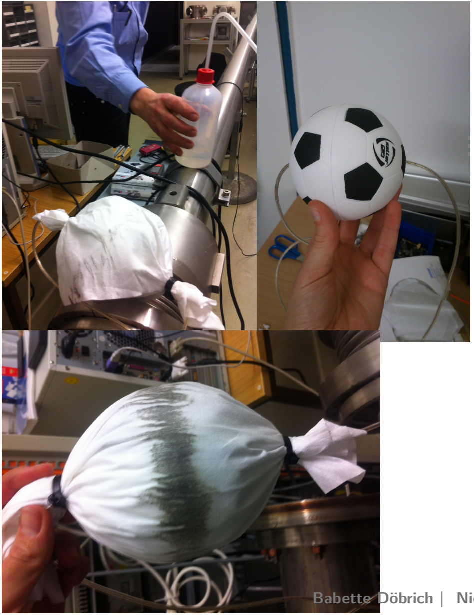

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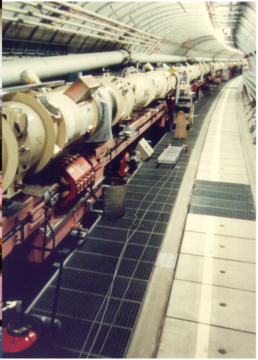

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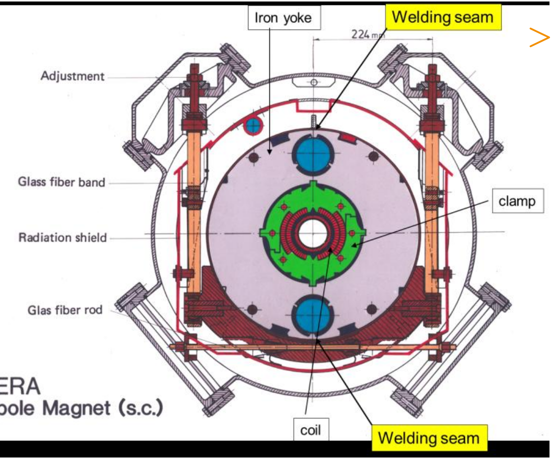
- reestablish “true aperture”?

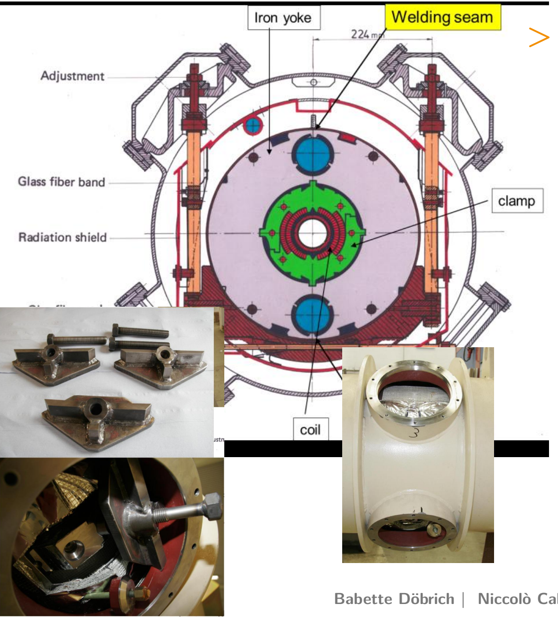
Outline

Magnet straightening in a (very small) nutshell



- howto
  - force on cold mass

Magnet straightening in a (very small) nutshell



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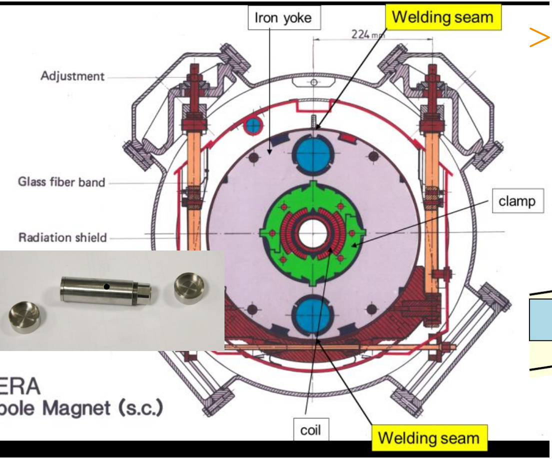

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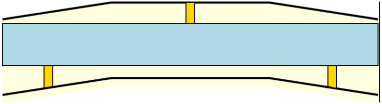
  - pressure prop at middle and ends



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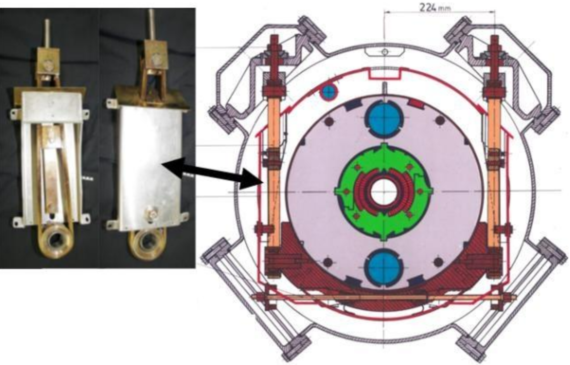

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Magnet straightening in a (very small) nutshell

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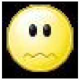
- good to know



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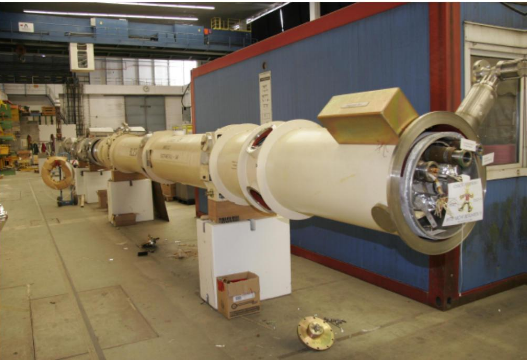

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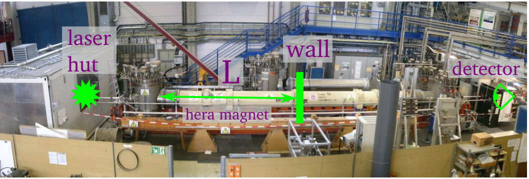

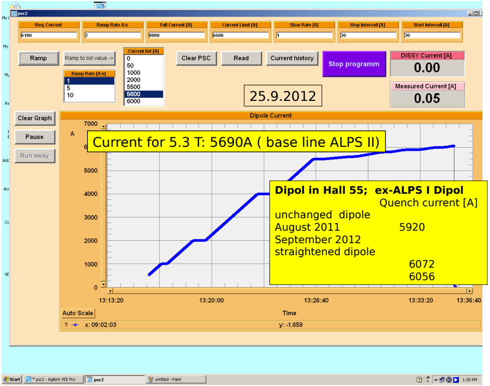

- howto
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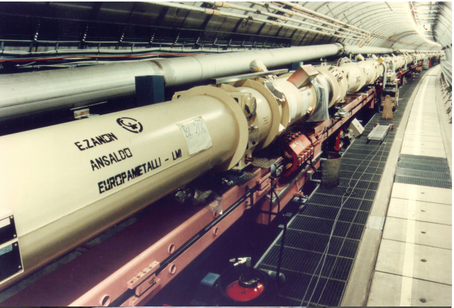
  - real-life tests with ALPS-I magnet

DESY

Magnet straightening in a (very small) nutshell



- howto
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  - pressure screws at lower flanches
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  - requires modified suspensions
- good to know
  - first tests with “PR” magnet (non-functional)
  - real-life tests with ALPS-I magnet
  - ultimate setup: 24 spare magnets (unused)
  - even reversible

Outline

> T/P: ALPS-II: Motivation, Goals and Tools Overview

> E: Laser and optics

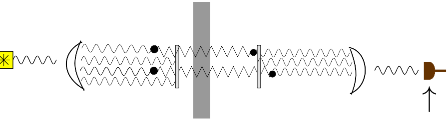
> E: Magnet system

> **E: Detection system**

> More on helio- and haloscopes

> Closing words

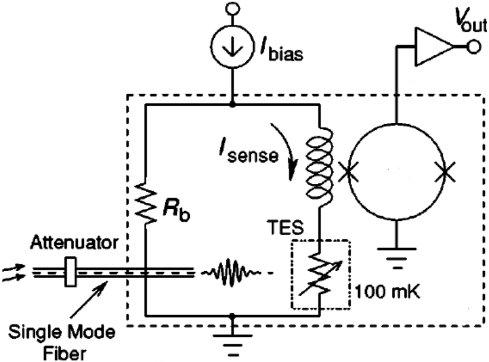
Detector requirements and TES working principle

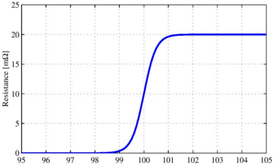


- Experimental needs
  - low rates of single infrared photons (<1/h)
  - high quantum efficiency
  - low background

Detector requirements and TES working principle

pic ad.: Miller Appl.Phys.Lett. 83/4





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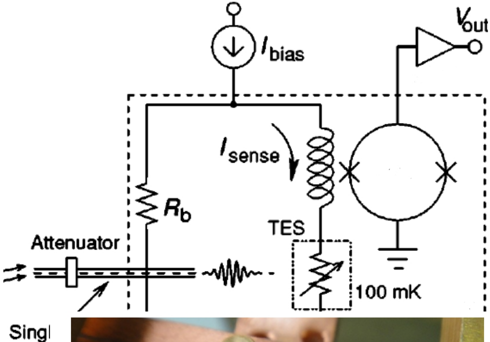

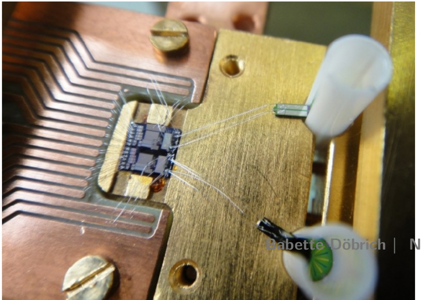

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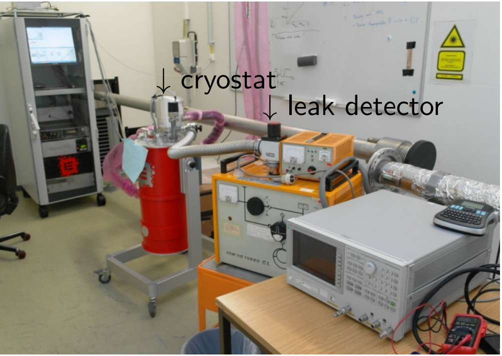
  - TES from NIST (and AIST) coated e.g. Tungsten (∼ 100mK) or Ti/Au (∼ 200mK)

Milli-Kelvin environment

↓ control rack



- ‘Entropy’ mK environment
  - dry (helium confined) & compact (only water & electricity)
  - time at <100mk: 48h
  - recharge time 1h

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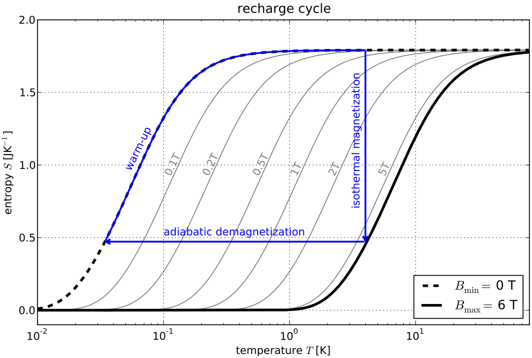

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  - isothermal magnetization, adiabatic demagnetization

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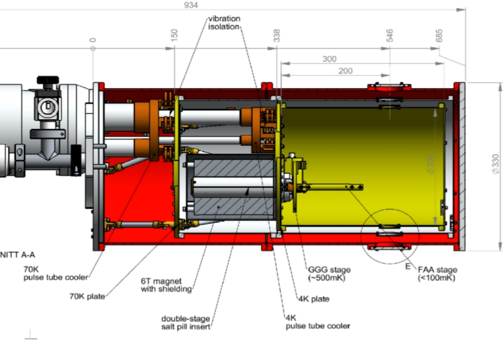

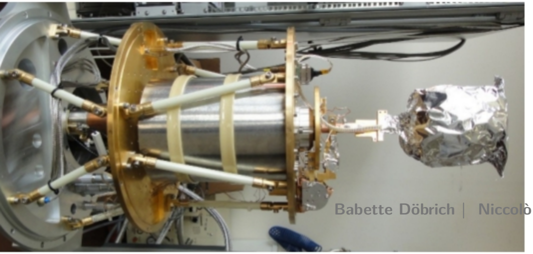

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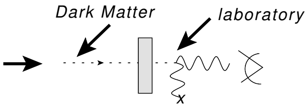
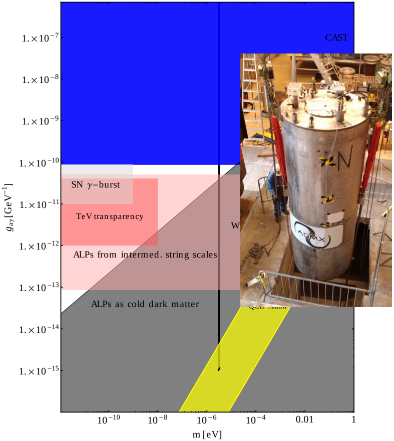
> Closing words

Dark Matter WISPs (Haloscopes)





- Axions & some other WISPs [1201.5902] → perfect dark matter candidate → Haloscope cavity [Sikivie '83]
- paradigmatic for axions: ADMX at Washington
  - ☺ VERY sensitive
  - ☹ so far very narrow band

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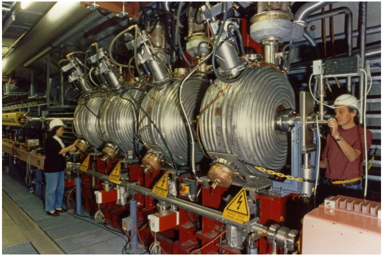

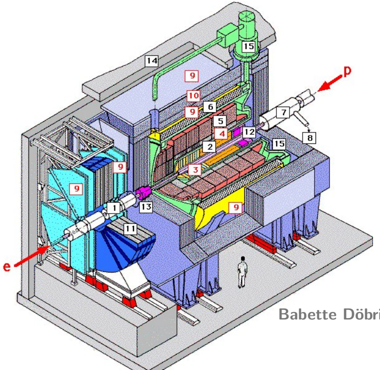

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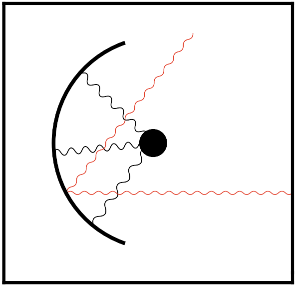

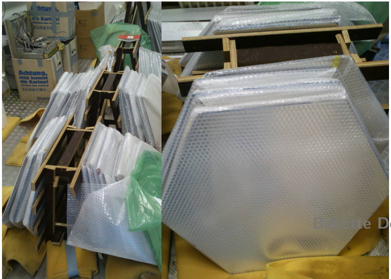

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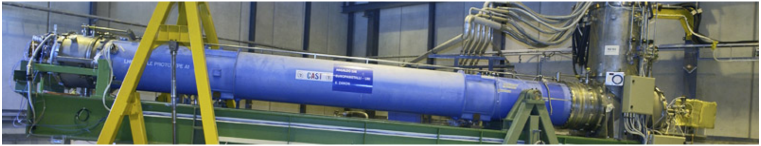
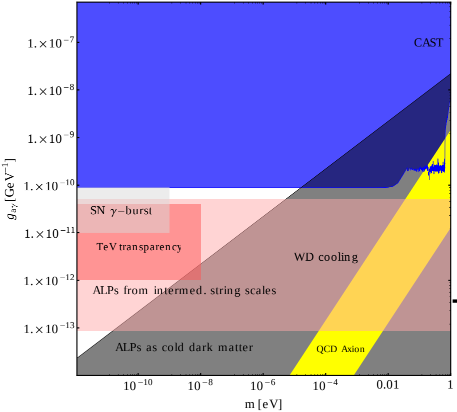
- WISP-DMX (Andrei Lobanov) at DESY for hidden photon DM and axion-like particle DM
- broadband searches with dish and detector at *center* [1212.2970]
- many ideas... little time! ;-)

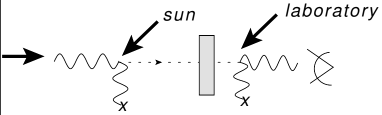
WISPs from our sun (Helioscopes)



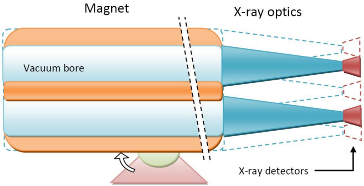


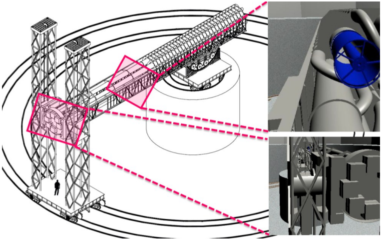
- natural photon source: sun
  $\rightarrow$ Helioscope [Sikivie '83]
- paradigmatic CAST@CERN

[arXiv:1209.6347]

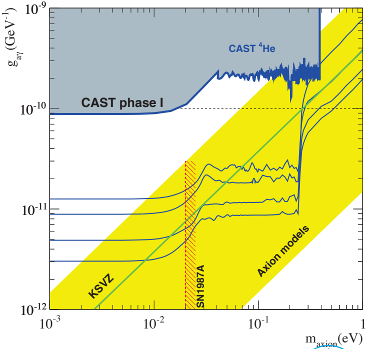


IAXO – the first custom made WISP search





> The International Axion Observatory: Helioscope Toroid reaching $g_{\phi\gamma} \sim 10^{-12}\mathrm{GeV}^{-1}$ I. Irastorza, see [1201.3849] and [1302.3273]



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Take-home messages

Albert-Einstein-Institut Hannover

UHH

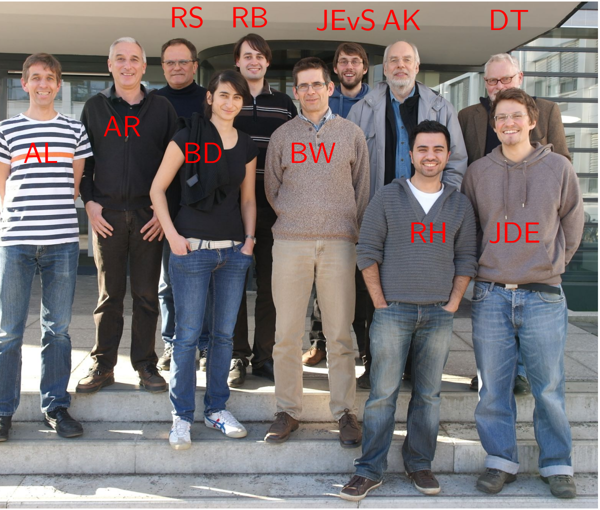
DESY

ALPS-II...

- looks for light beyond-Standard-Model particles with the 'light-shining-through-a-wall' principle
- complements well other searches
- combines a variety of techiques and methods (single photon detection, high-finesse cavities, accelerator infrastructure..)
- strives towards discovery (or exclusion) of new particles in 3 stages in the following 4-5 years

DESY

The ALPSians



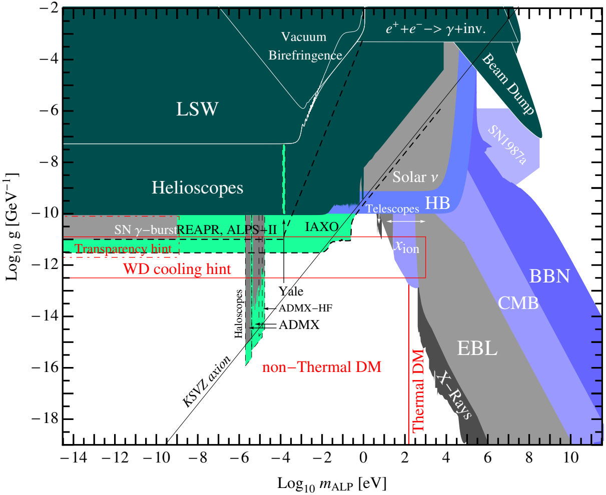
- *Optics:* Benno Willke (staff AEI) Robin Bähre (PhD, AEI), Reza Hodajerdi (PhD, DESY), Samvel Ghazaryan (staff)
- *Magnet/Site:* Dieter Trines + team
- *Detector:* Dieter Horns (staff HH), Friederike Januschek (Postdoc), Jan Dreyling-Eschweiler, Jan-Eike von Seggern (PhD)
- *Safety/Eng.:* Richard Stromhagen
- *Howto:* Ernst-Axel Knabbe (staff)
- *Science case & miscellanea:* Axel Lindner, Andreas Ringwald (staff), Babette Döbrich (Postdoc)

More?

Bonus material

Comprehensive ALP exclusion plot

whole story see e.g. [arXiv:1205.2671]

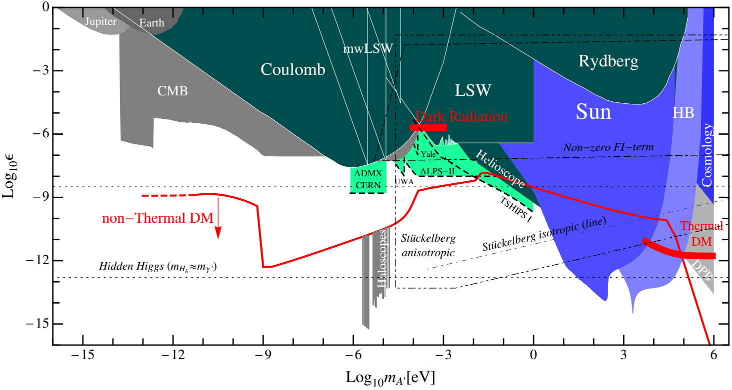


colored regions:

- Dark green = experiments
- blue: astrophysical/ cosmological
- gray: astronomical
- light green: planned exp.
- red: favored parameter regions

Comprehensive HP exclusion plot

whole story see e.g. [arXiv:1205.2671]



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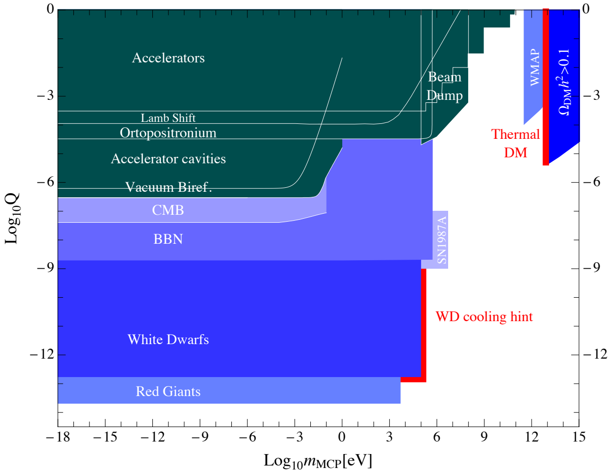
Comprehensive MCP exclusion plot

whole story see e.g. [arXiv:1205.2671]



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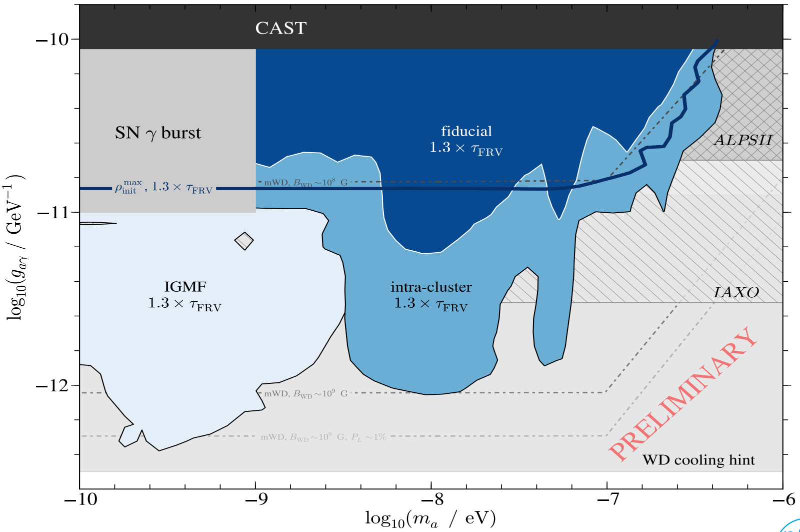
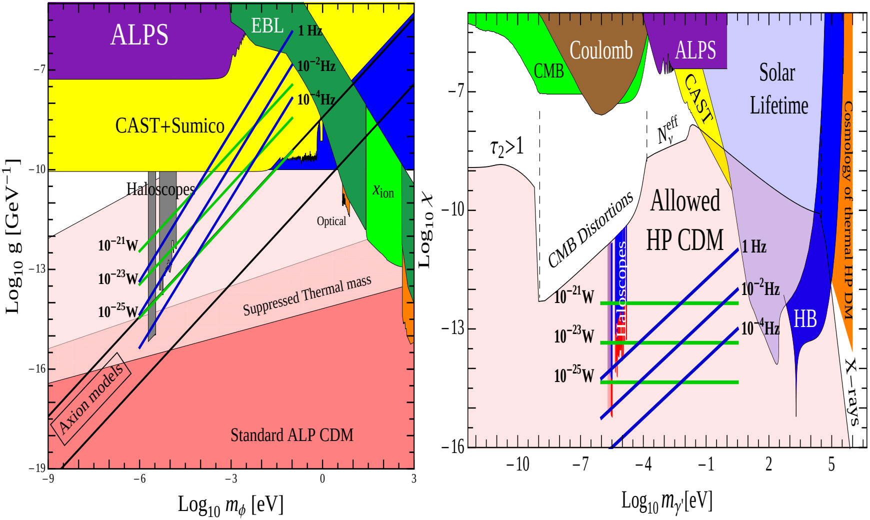
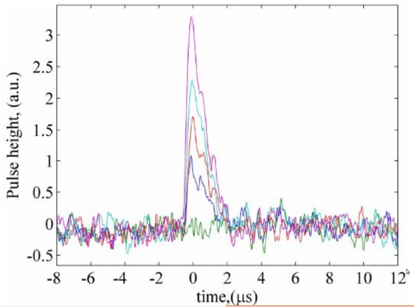
TeV transparency recent data [arXiv:1302.1208]



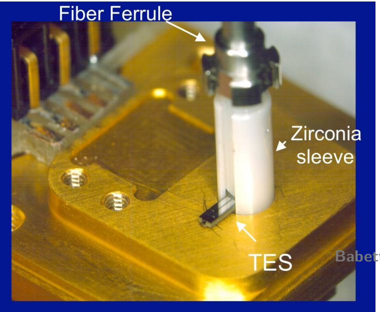
Dish


ALPS
EBL
1 Hz
10^{-2}Hz
10^{-4}Hz
CAST+Sumico
Haloscopes
10^{-21}W
10^{-23}W
10^{-25}W
Optical
x_{ion}
Suppressed Thermal mass
Axion models
Standard ALP CDM
$\mathrm{Log}_{10}\, g\ [\mathrm{GeV}^{-1}]$
$\mathrm{Log}_{10}\, m_\phi\ [\mathrm{eV}]$
CMB
Coulomb
ALPS
CAST
Solar Lifetime
N_ν^{eff}
$\tau_2>1$
CMB Distortions
Allowed HP CDM
Haloscopes
1 Hz
10^{-2}Hz
10^{-4}Hz
10^{-21}W
10^{-23}W
10^{-25}W
HB
Cosmology of thermal HP DM
X−rays
$\mathrm{Log}_{10}\, \chi$
$\mathrm{Log}_{10}\, m_{\gamma'}[\mathrm{eV}]$

Photon signal and TES coupling



Lita et al., Opt. Express, Vol. 16, 5 (2008)



- single photon signals
- time/ energy resolution $\sim 1\mu s / \sim 0.1\text{eV}$, quantum efficiency up to 99% Lita et al., Proc. SPIE 681, 76810D (2010)
- not very fast, but almost background free
- good timing resolution valueable in case of unstable lock
- SQUID array acts as transimpedance element