Lab-search for ultralight 'hidden photons' at DESY Hamburg and Karlsruhe Institute of Technology

Babette Döbrich (CERN) presenting work of the ALPS-II and FUNK collaborations

Photon 2015 Novosibirsk

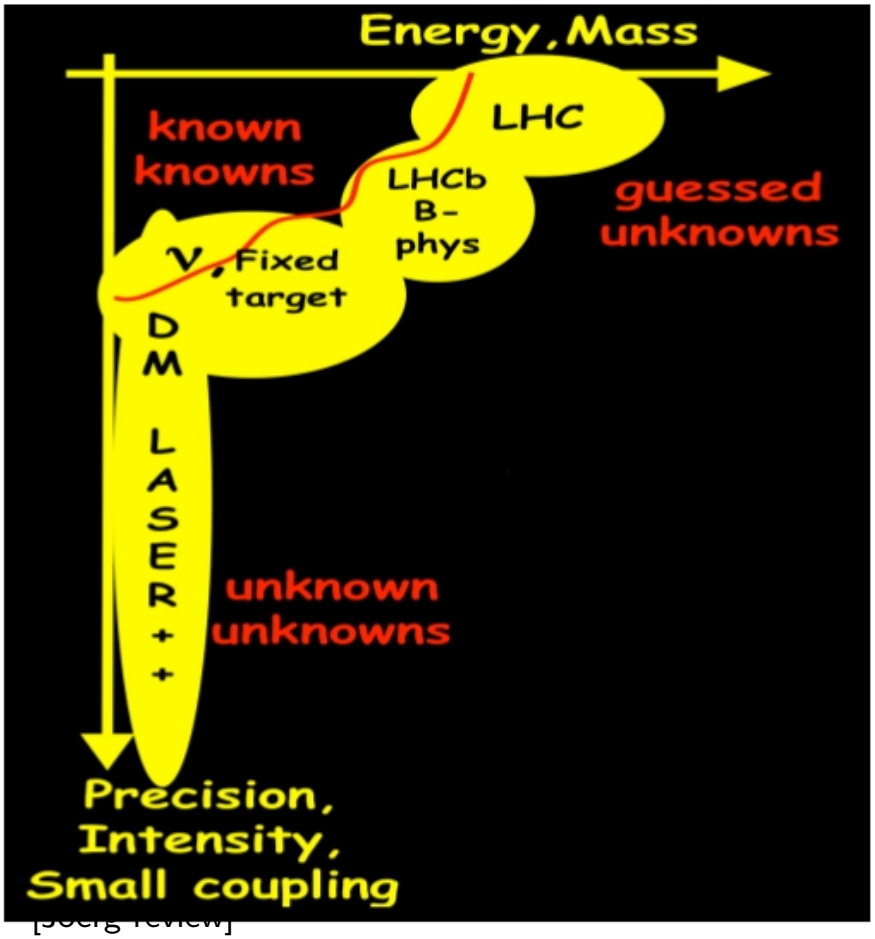
Outline

1. Why and How: Hidden Photons
2. ALPS-II at DESY Hamburg (indirect search)
3. Finding U(1)s of a Novel Kind (FUNK) at KIT (direct DM)

Hidden Photons (HPs) & Weakly interacting slim particles

Physics beyond SM needed
e.g. Dark Matter...

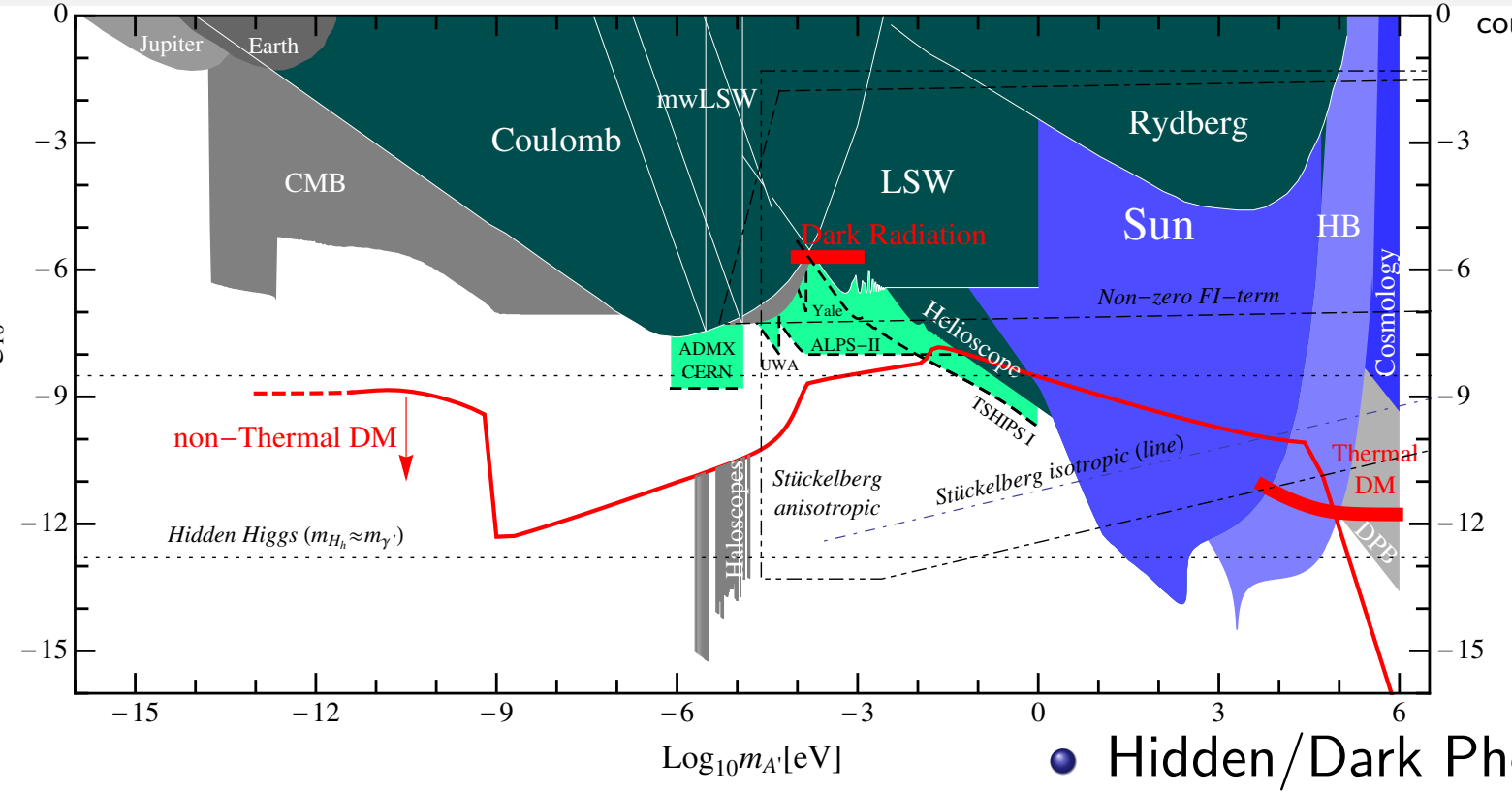
[courtesy of J.Jaeckel]



[Joerg review]

- light particles can, e.g. occur from symmetry breaking at high energy scales (prominent QCD **axion** $\mathcal{L} \sim g\phi\vec{B}\vec{E}$ and ALPs)
- $\rightarrow$ 'WISPs' (class of experiment with or w/o magnetic field)
- 'small-ish' setups: sub-eV (no focus on: collider, cosmo)

Hidden Photons (HPs) & Weakly interacting slim particles



- Hidden/Dark Photons

  $\mathcal{L} \sim \chi F_{\mu\nu} X^{\mu\nu} + \frac{m_{\tilde{\gamma}}^2}{2} X_\mu X^\mu \rightarrow$ extra U(1) with mass, Stückelberg or Hidden Higgs

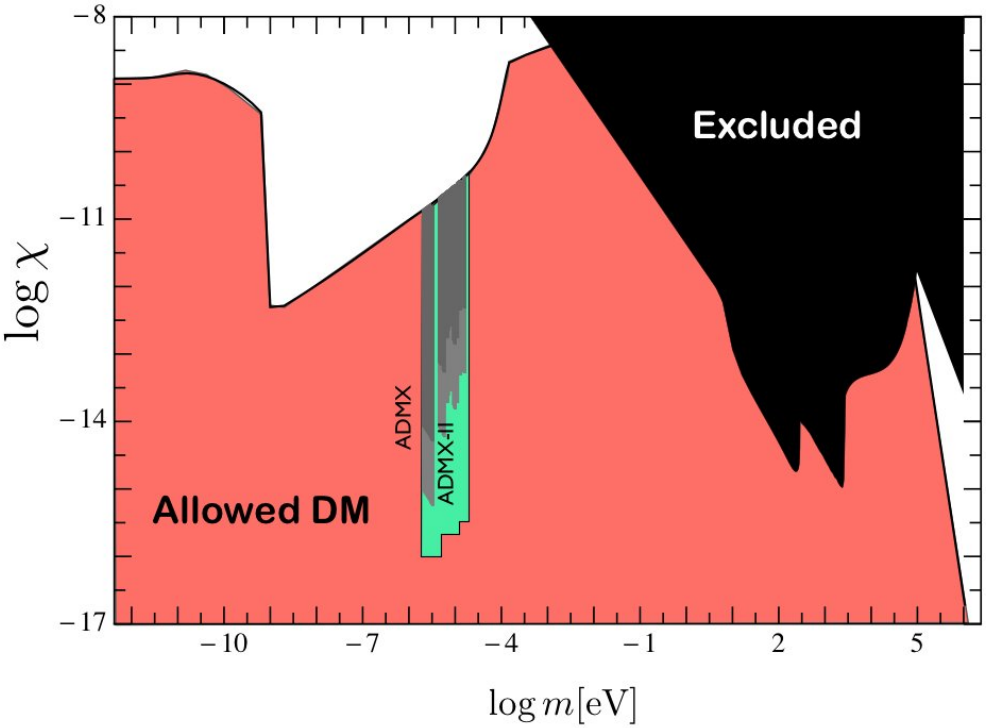
- HPs e.g. from string scenarios [1206.0819], Dark Matter (see below)

↑ Remember Shape of the RED LINE

spontaneous γ-γ' oscillation

ultra-light Hidden Photons as cold Dark Matter

[figure below from 1311.5341]



- WIMPs are a good but by far not the only cDM candidate
- [Nelson/Scholtz Phys.Rev. D84 (2011) 103501], [Arias et. al, JCAP 1206 (2012) 013] $\longrightarrow$ naively $p \sim T_{\mathrm{today}} \sim$meV
  misalignment:
  $p \sim H \sim 10^{-33}\ \mathrm{eV} \ll T$
- [Graham et al, 1504.02102] $\longrightarrow$ inflationary fluctuations
  $m \approx 10^{-5}\mathrm{eV} \times (10^{14}\mathrm{GeV}/\mathrm{H_I})^4$
- so far, parameter space relatively wide (theory!) $\rightarrow$ need many experiments
- indirect & direct searches

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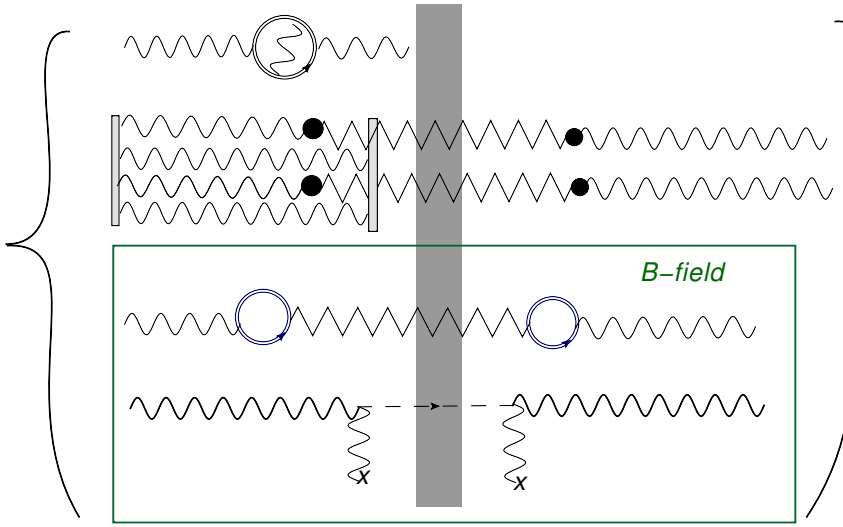
Light-Shining Through Wall with ALPS-II

Any Light
Particle Search I

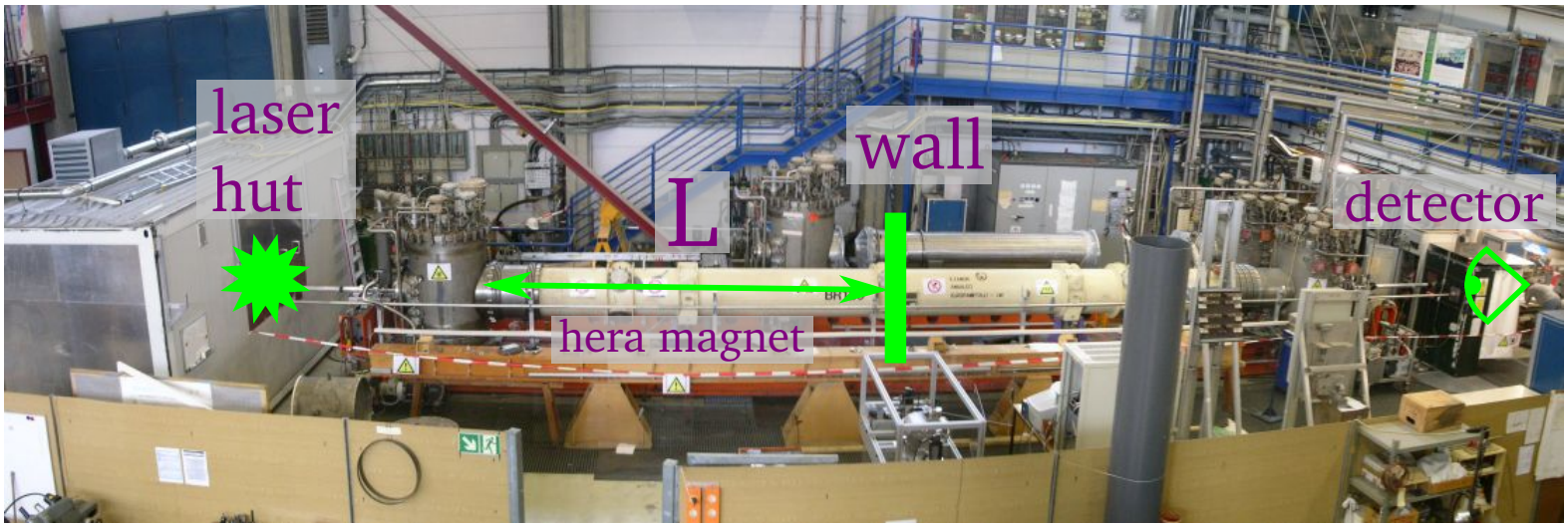
Fabry Perot ↗
resonator
before "wall"



HP search → no B-field

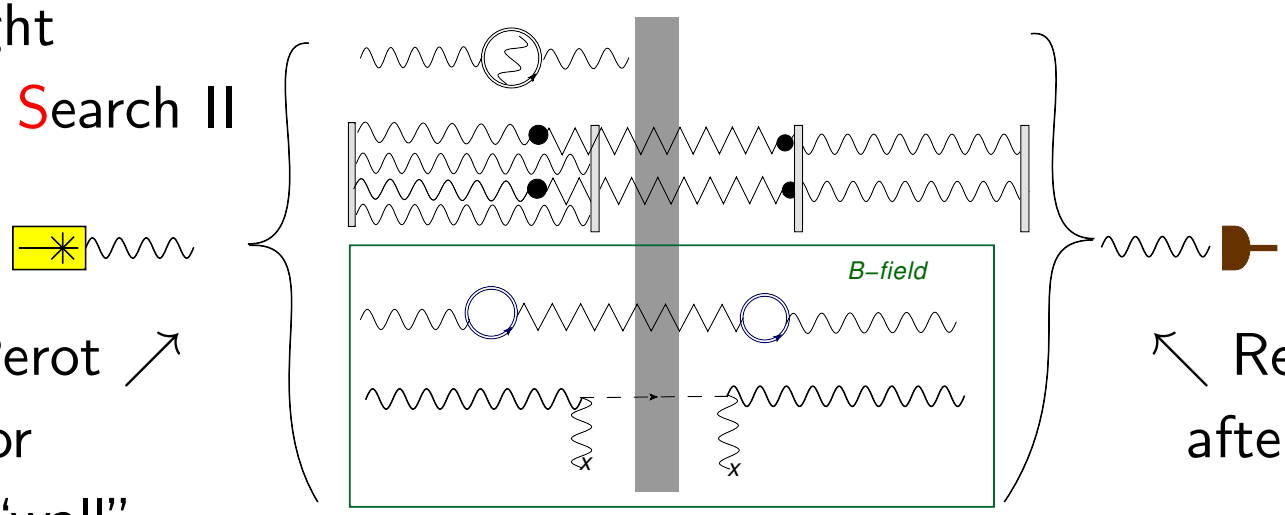
ALP search → B-field

9m, 5T
HERA
dipole



Light-Shining Through Wall with ALPS-II

Any Light
Particle Search II



Fabry Perot ↗ resonator before "wall"

↖ Resonator after "wall"

Upgrades

1) more photons → enhanced probability
2) better single photon detection

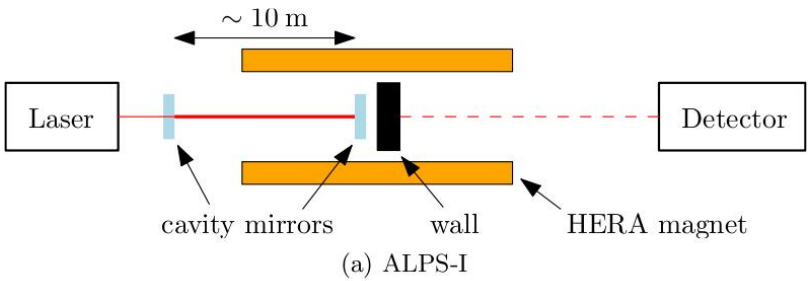
1) *coupled* cavities → resonant regeneration (photon self-interference)
2) Transition Edge Sensor - superconducting edge

Light-Shining Through Wall with ALPS-II

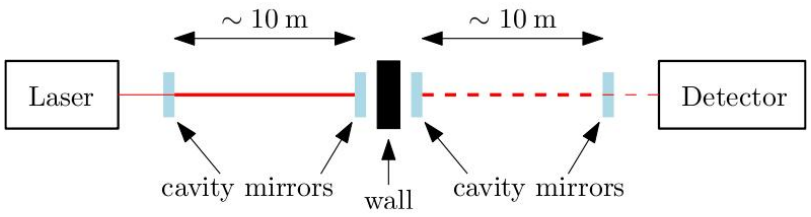
3) More (magnetic) length (for Axion Like Particles)

3) more HERA dipoles (20)! enhance length $\rightarrow$ tunnel

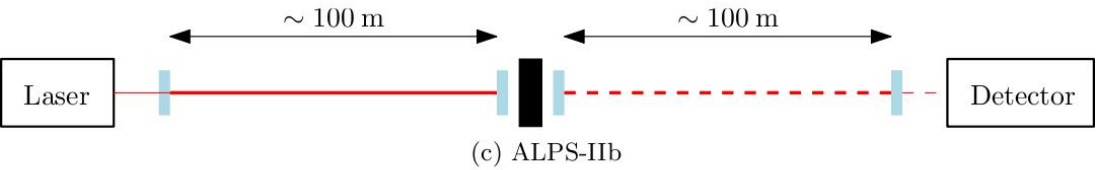
Status of ALPS-II and first performance results



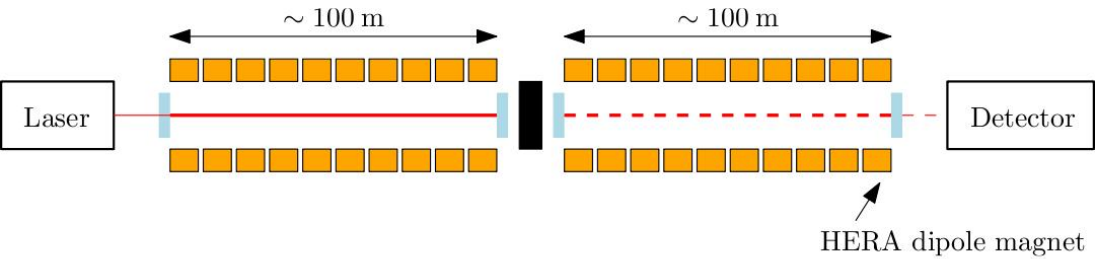
(a) ALPS-I



(b) ALPS-IIa



(c) ALPS-IIb



(d) ALPS-IIc

- stages ALPS-II **a**,(b),c (only c has magnets!)

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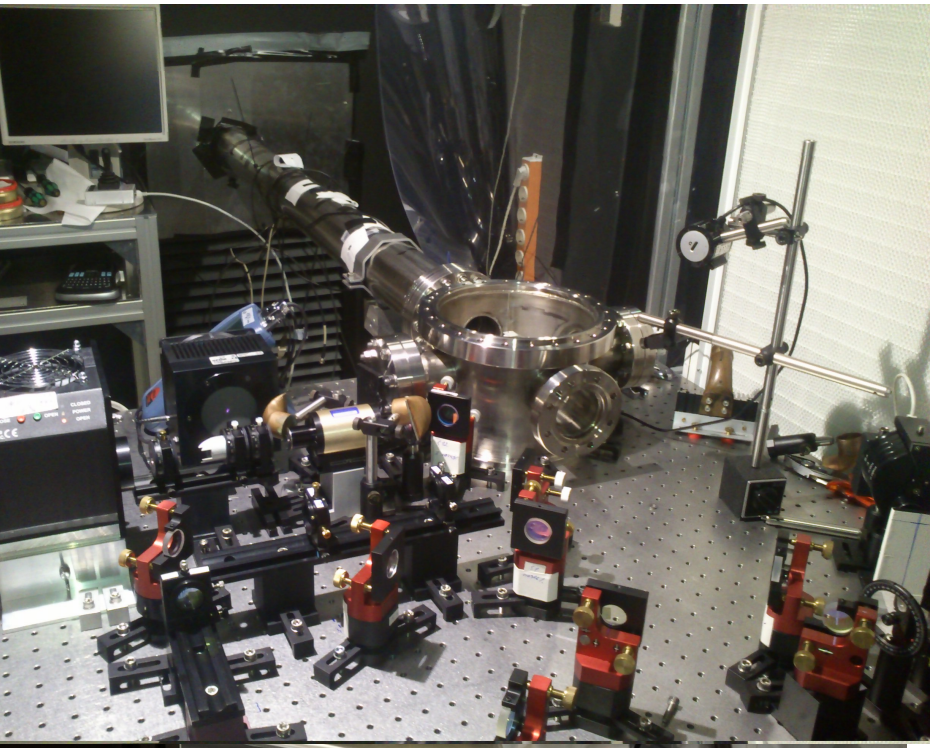

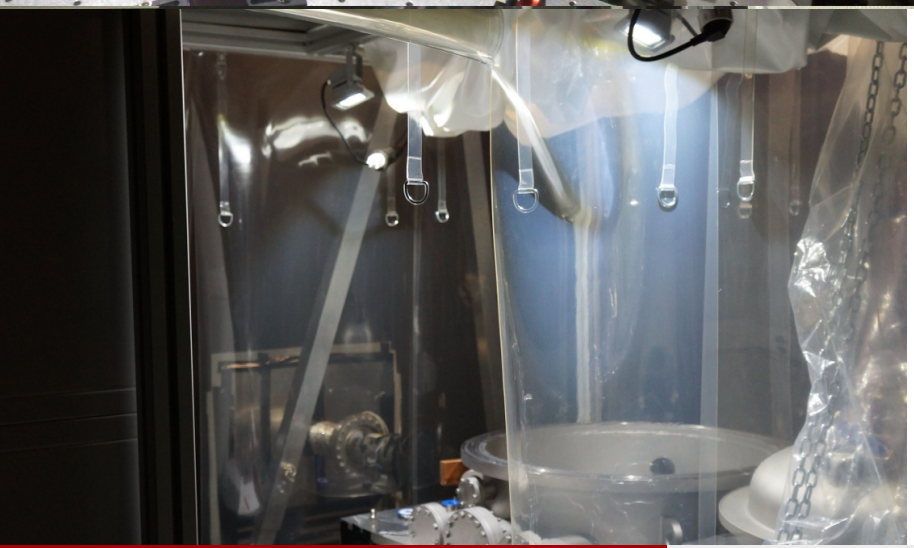

- stages ALPS-II **a**,(b),c
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- **Optics:** high-finesse cavity 1064nm
  across 20m at DESY

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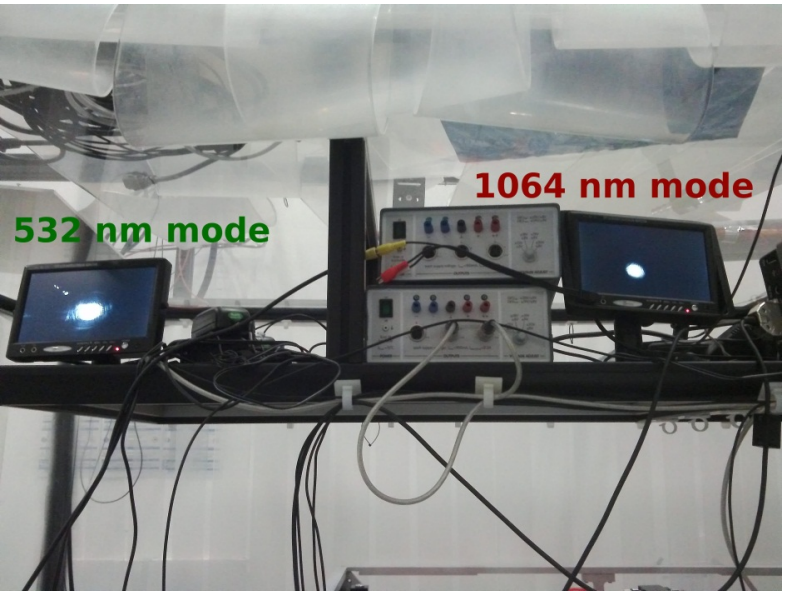

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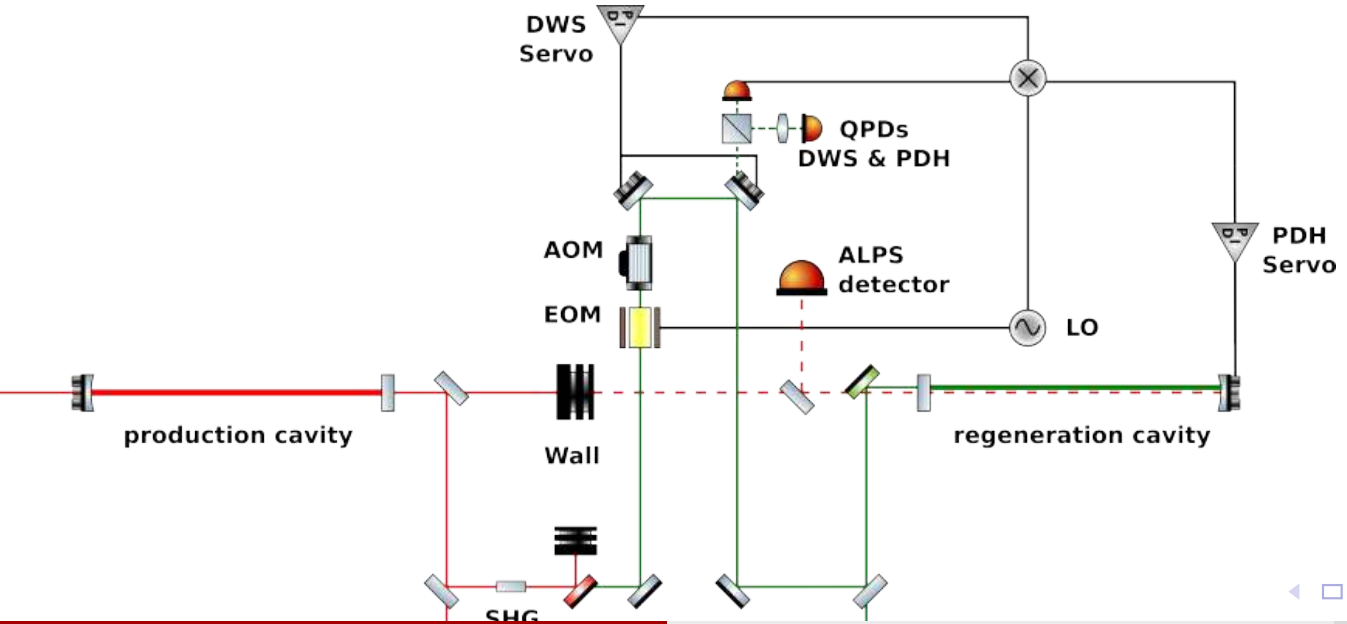

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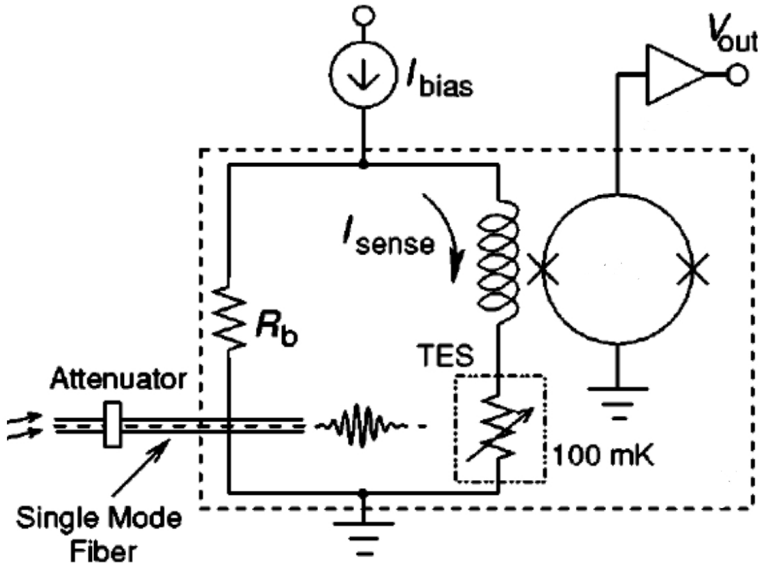

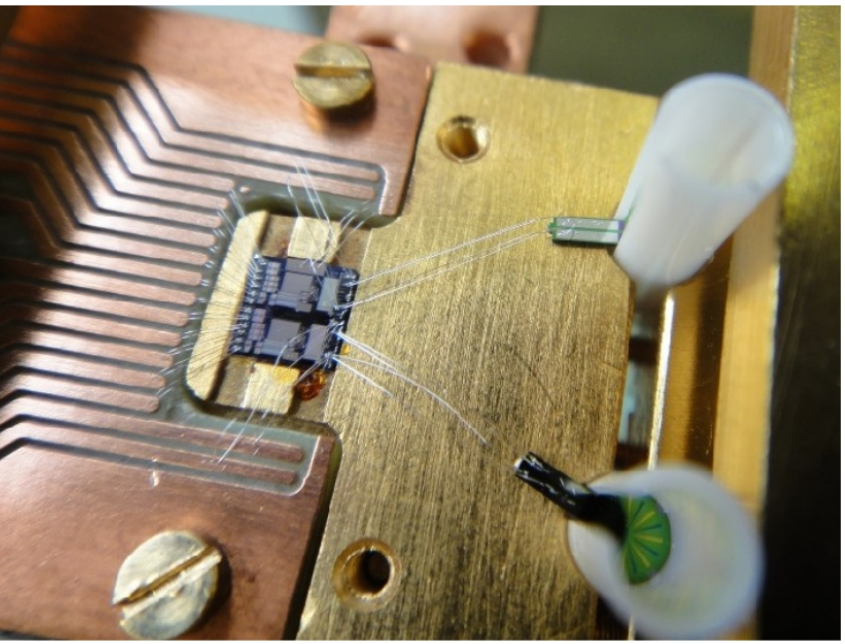

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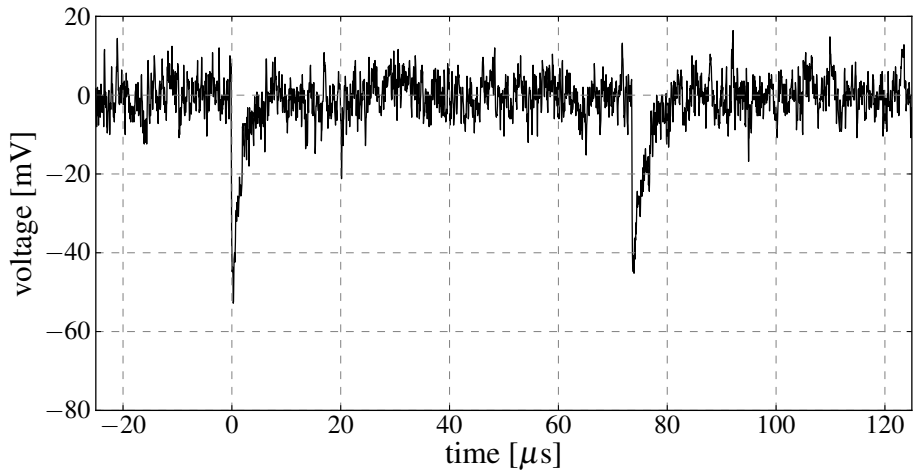

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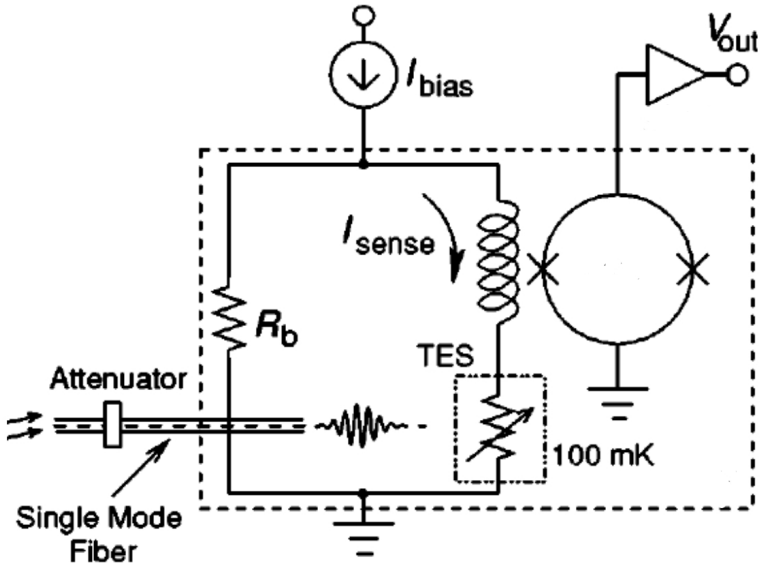

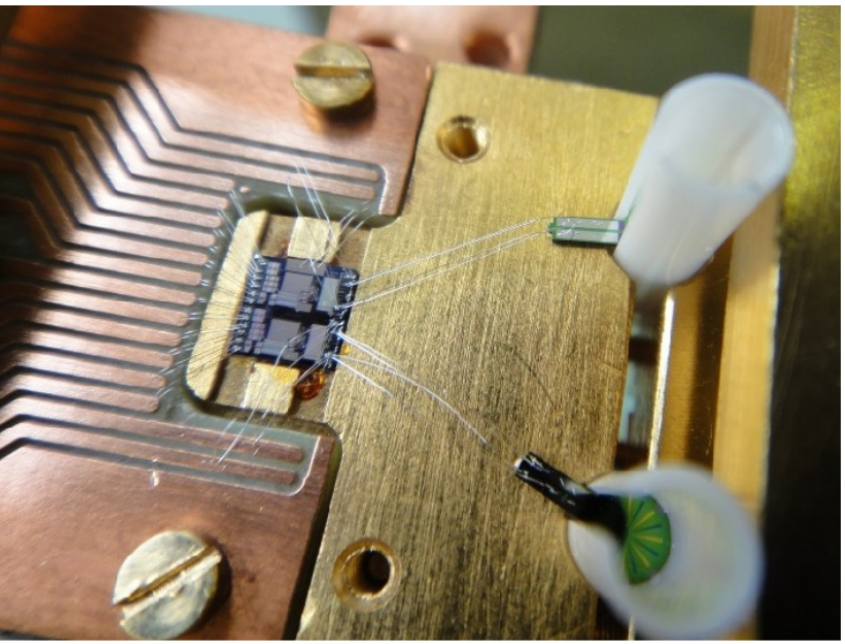

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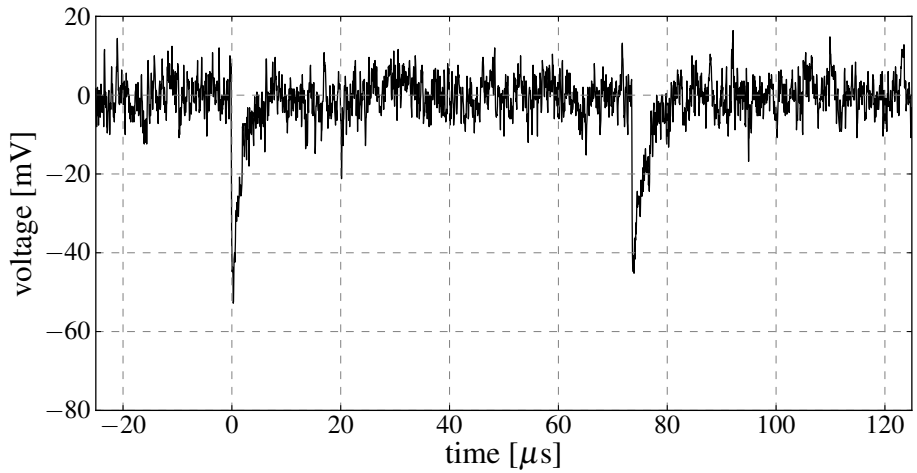

Status of ALPS-II and first performance results

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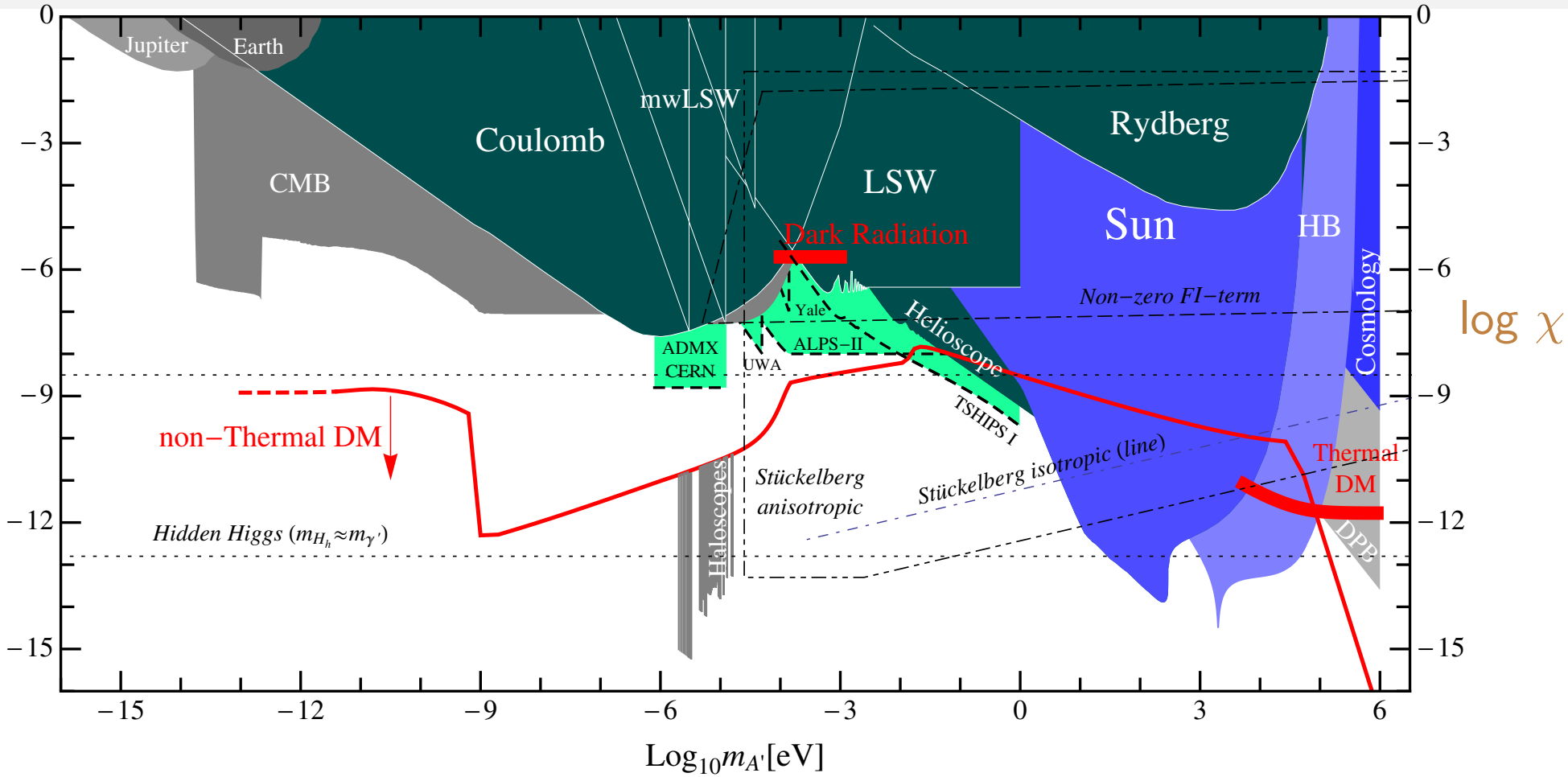
- **(Magnets:)** 'magnet straightening' working just fine (aperature needs to restored to fit photon beam) Dieter Trines

Status of ALPS-II and first performance results



- First HP measurements beginning 2016? (replacement of faulty mirrors)

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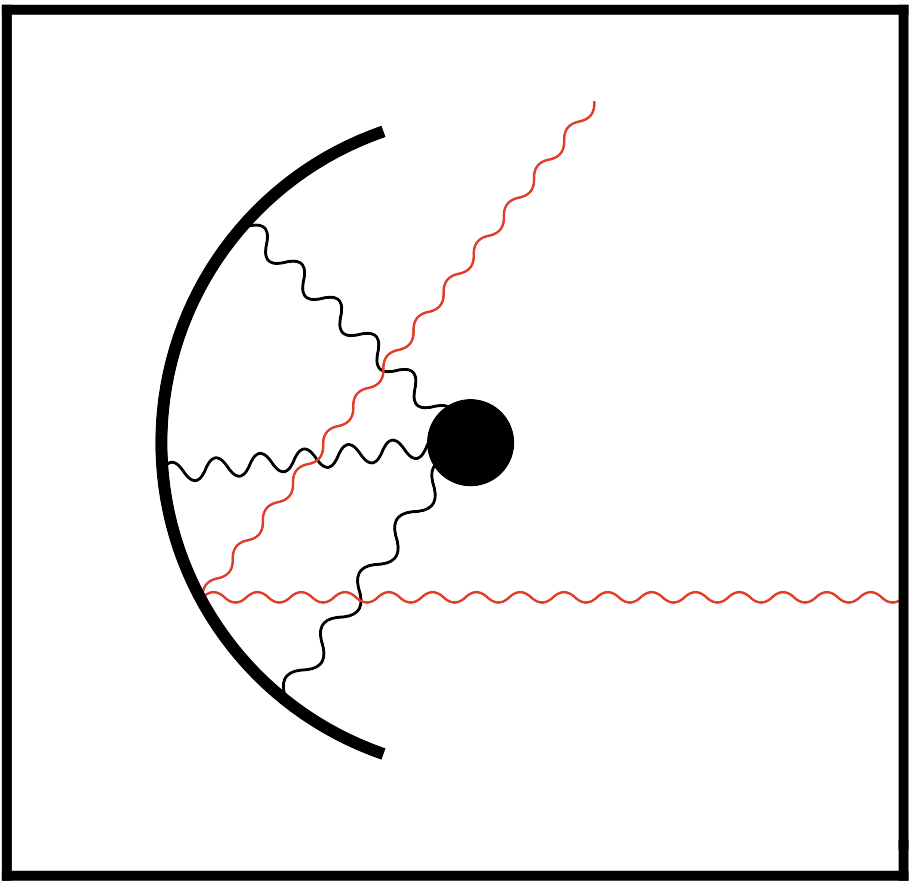
Dish antenna Dark Matter concept Horns et al. JCAP 1304 (2013) 016

Artist's view of the setup:



- Hidden Photon DM can effectively move conductor electrons → radiation
- background-supressed at dish! → collect light at center of reflecting sphere
- Directional information
- (Axions and ALPs need *strong* $\vec{B}$ ∥ surface, unlikely with what follows) Haloscopes (ADMX...) are the better option)

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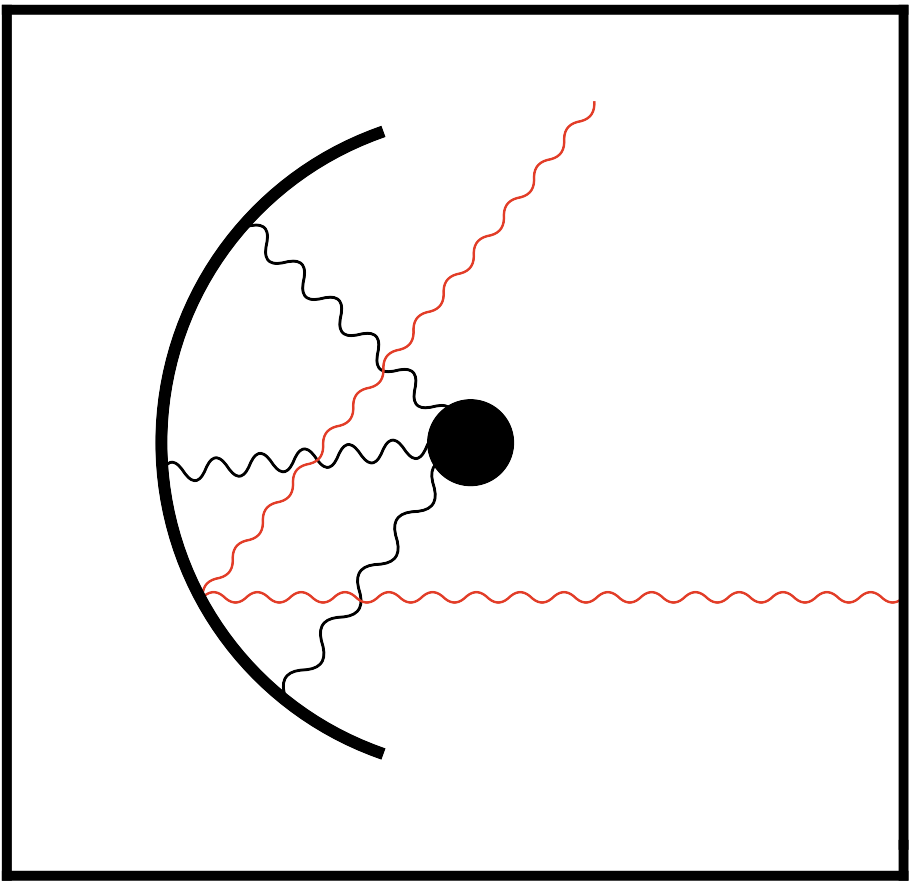

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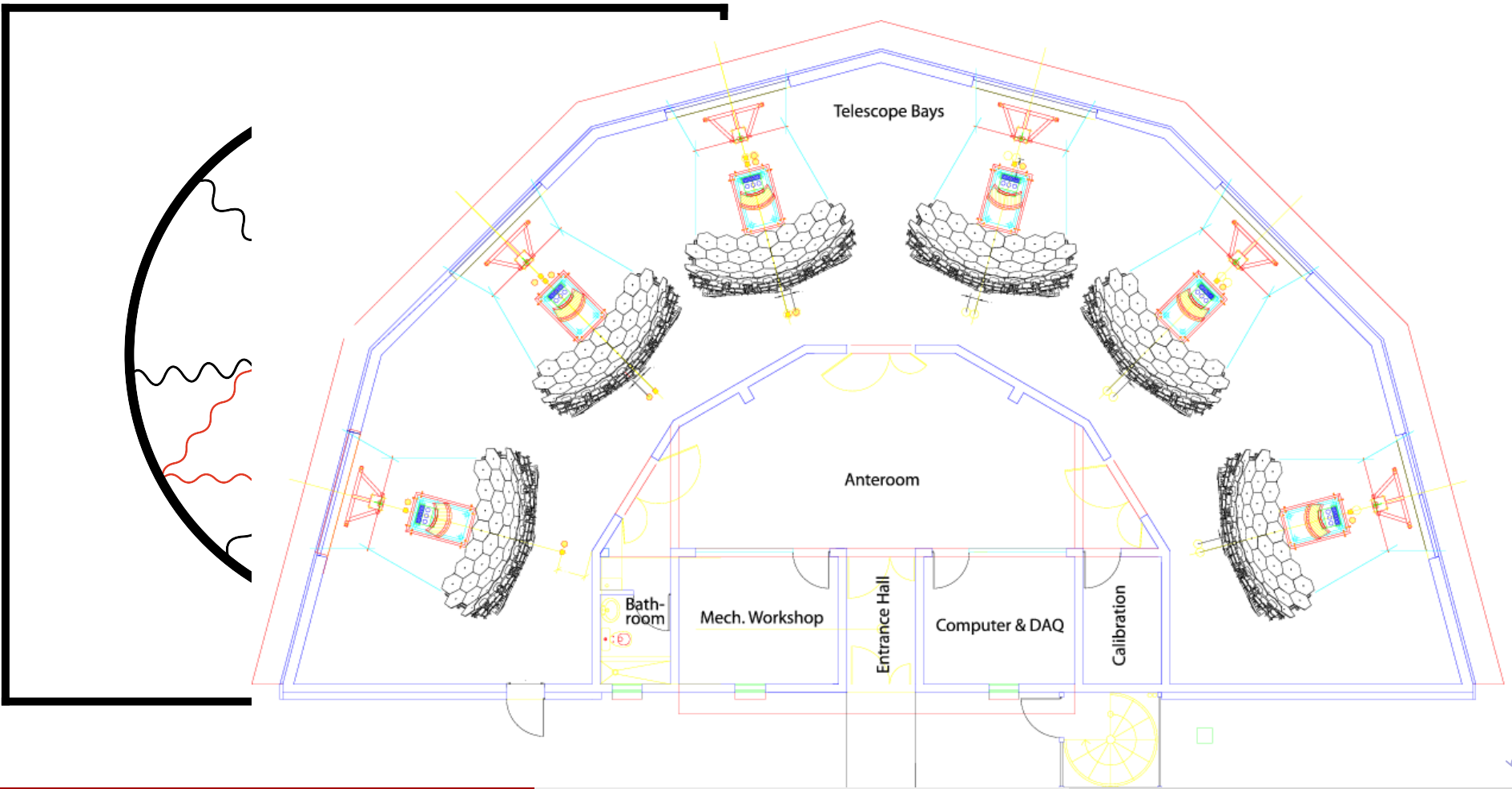
Dish antenna Dark Matter concept Horns et al. JCAP 1304 (2013) 016

Artist's view of the setup:

particle physicist's "view of the setup":



Mirror setup and adjustment at KIT, fall/winter 2014

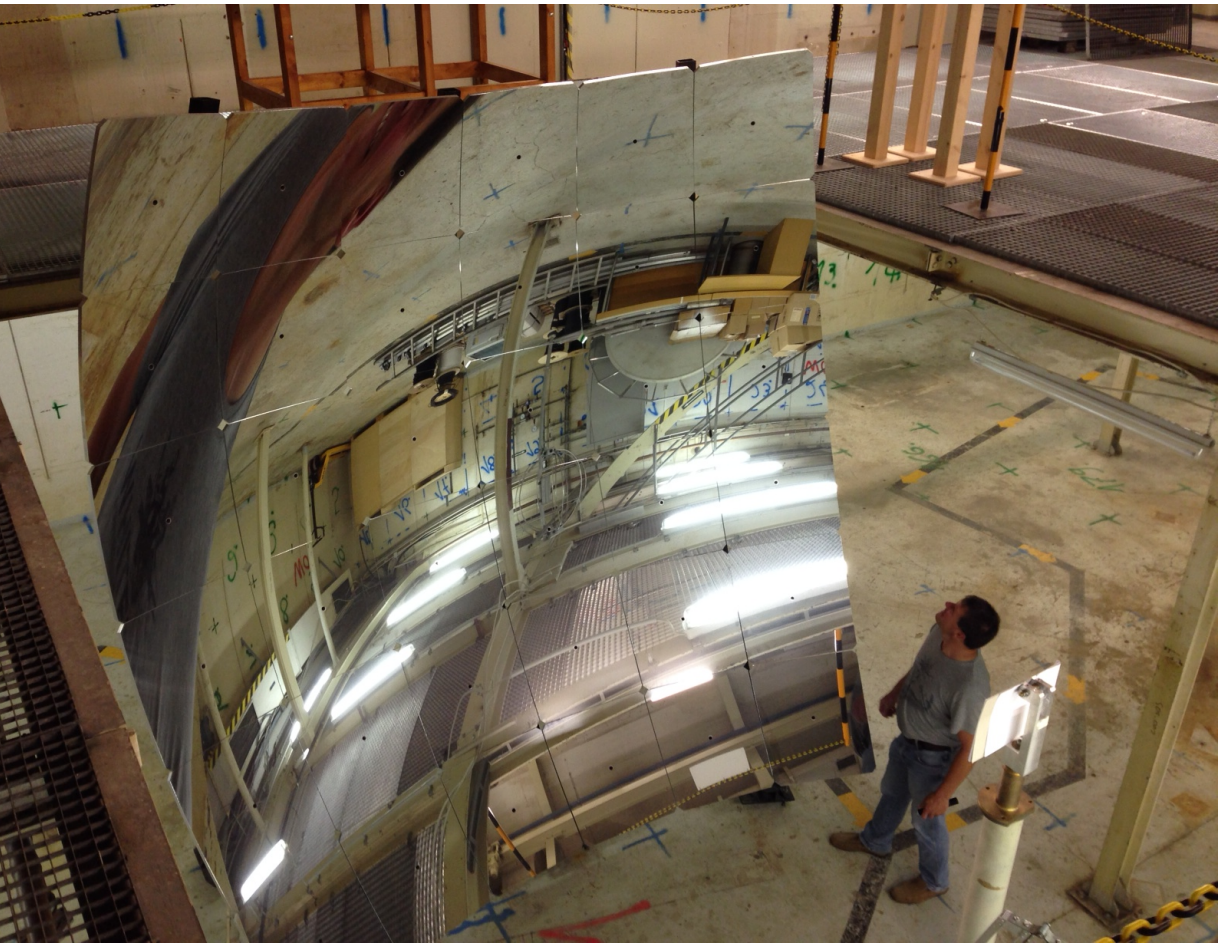
test elements of Pierre Auger mirror

mirror of 13 m^2 at KIT, ROC=3.4m

Mirror setup and adjustment at KIT, fall/winter 2014

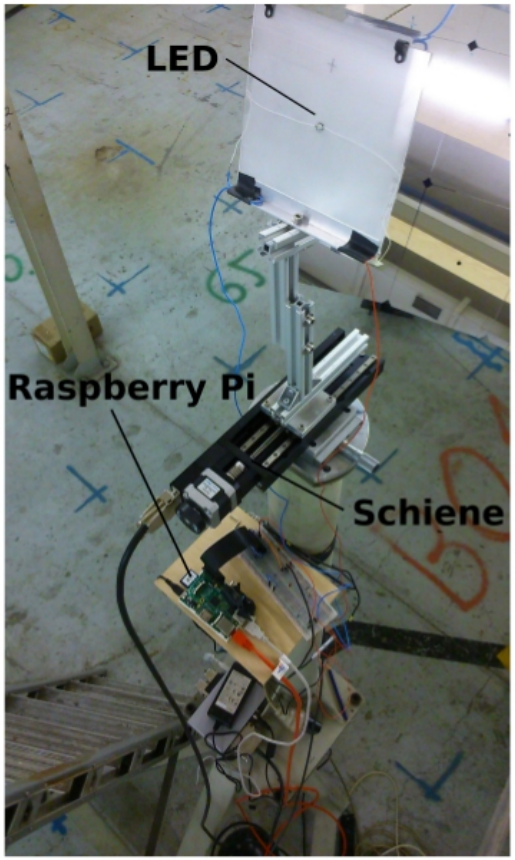
Set up in a former van-de-Graaff hall

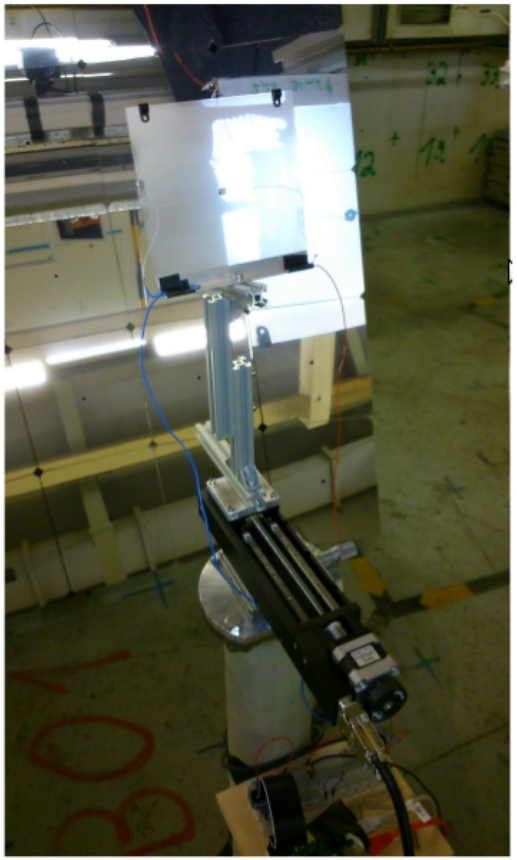
$\rightarrow$ thick walls, electromagnetically quiet



Mirror setup and adjustment at KIT, fall/winter 2014

Comissioning: Radius point search





stment at KIT, fall/winter 2014

curvature not perfect &

ROC of the individual elements $\pm$ 3 cm

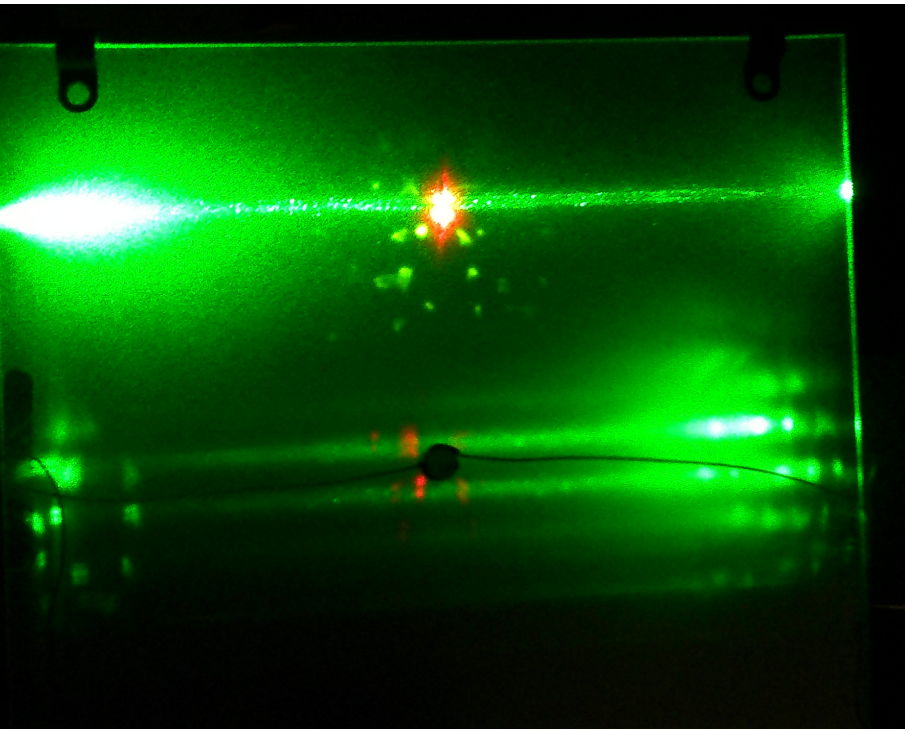
Go piece by piece!

Mirror setup and adjustment at KIT, fall/winter 2014

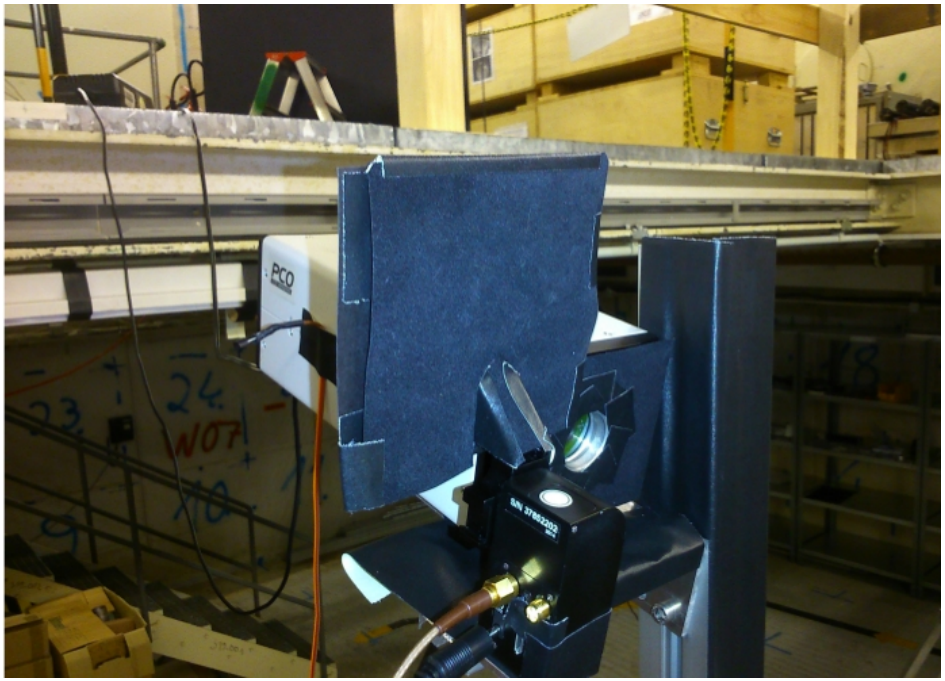
Mirror setup and adjustment at KIT, fall/winter 2014

spotradius from 7.5mm to 2.5 mm!

mark it $\rightarrow$ ready for measurement



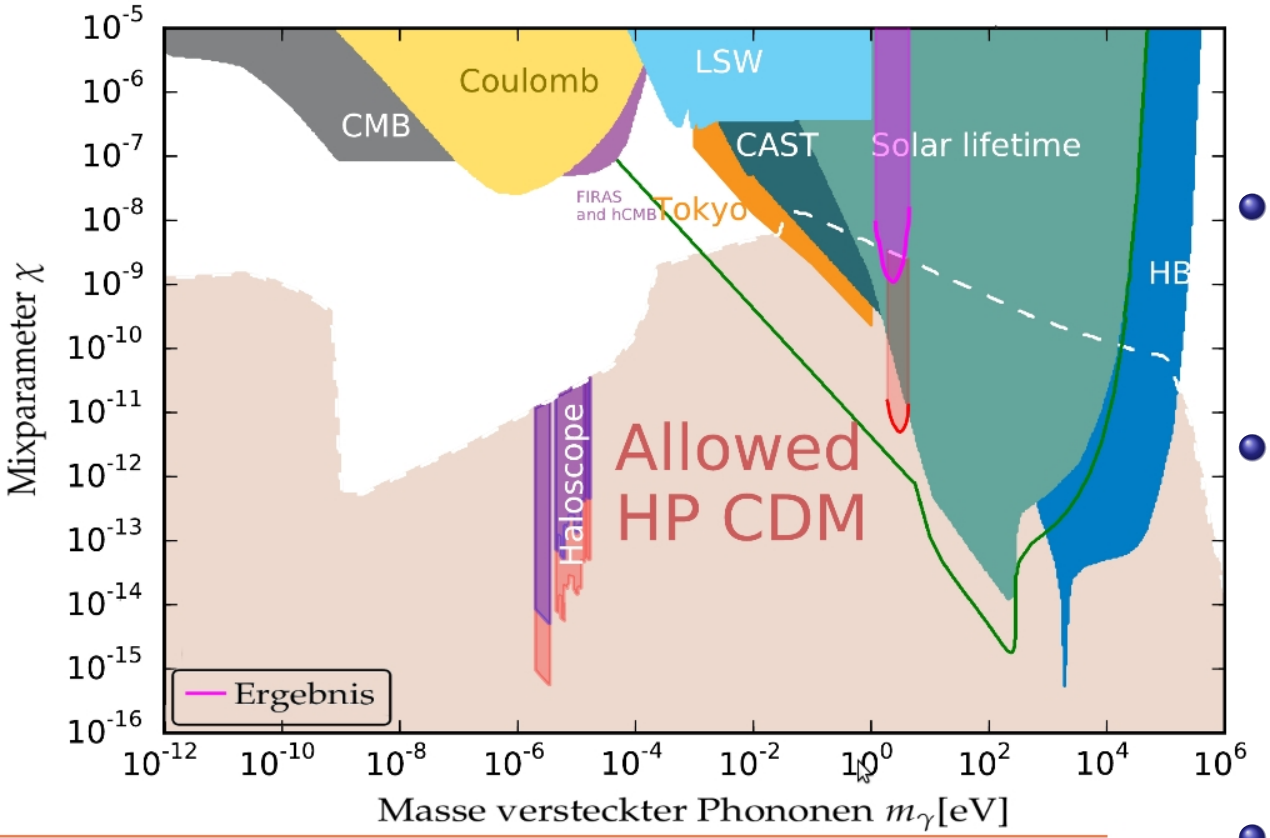
Measurements Jan-March 2015



- first step: SENSICAM CCD, understand background & temperature
- e.g. finding of nightly emergency lighting tests
- SENSICAM CCD rather noisy 0.1 e^-/px/s + 13 e^- readout $\rightarrow$ but many pixels illuminated!

Measurements Jan-March 2015

Red: Tokio 1504.00118, Pink: FUNK CCD



- first step: SENSICAM CCD, understand background & temperature
- e.g. finding of nightly emergency lighting tests
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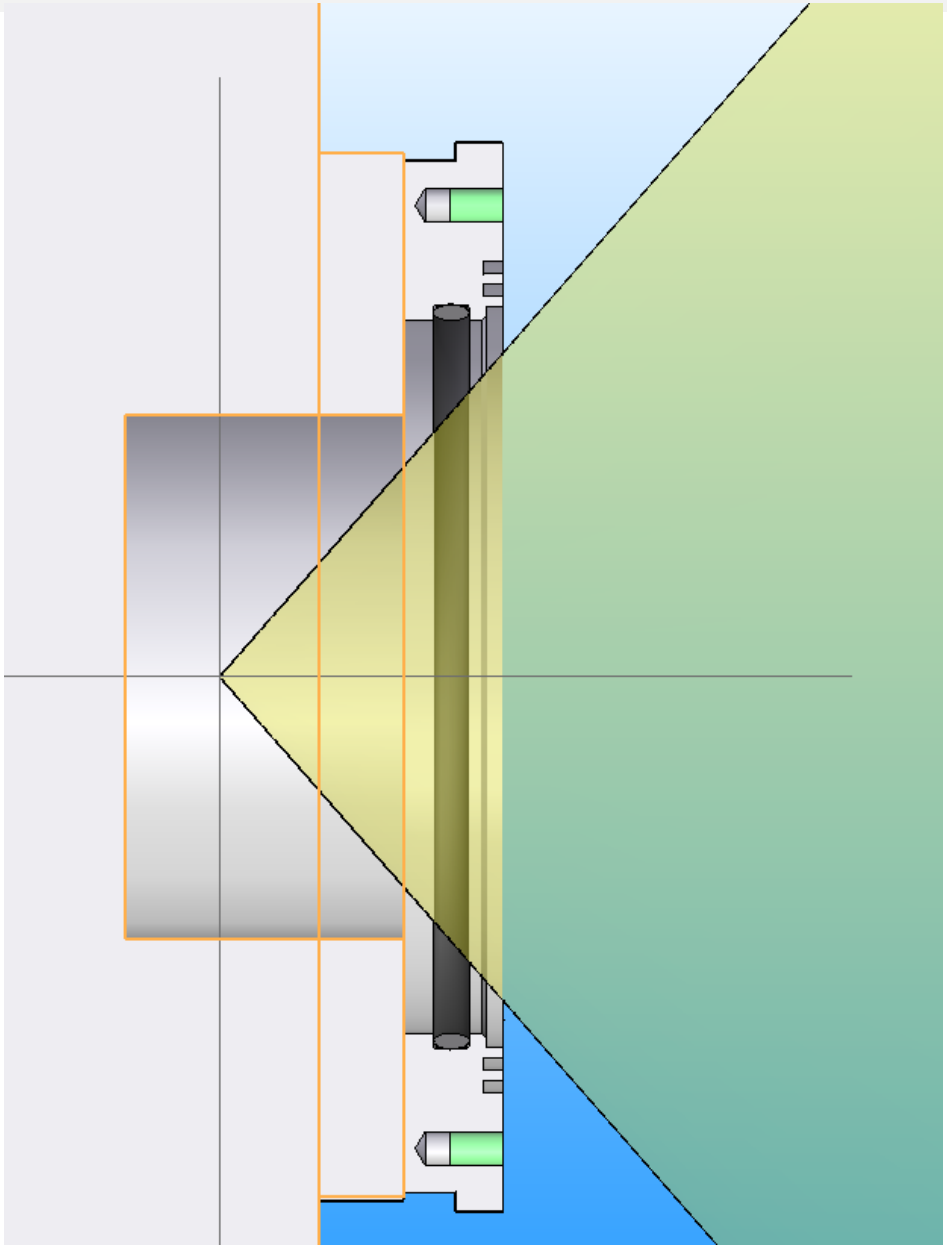
- first results in the Bsc thesis of Chr. Schäfer at KIT

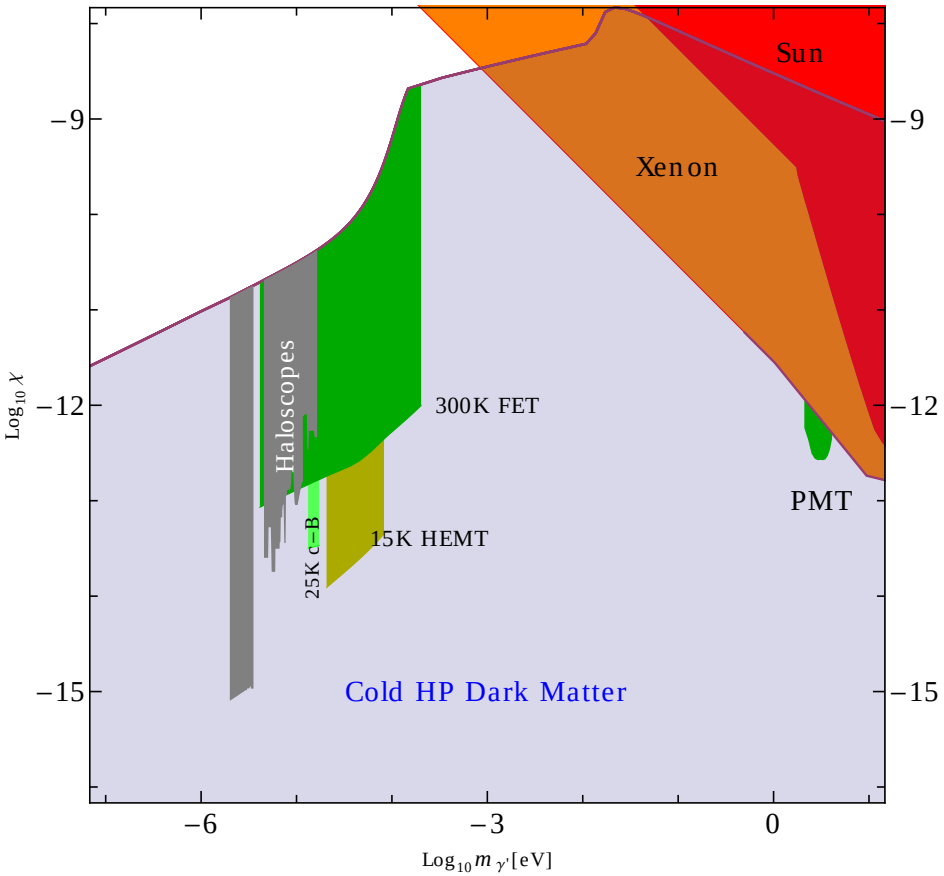
Next steps & on the longer run



- cooled Enterprise PMT 9107 with $\sim 1 - 3$Hz Dark noise delivered at 25mm active diameter
- detector is being characterized, shutter tested...

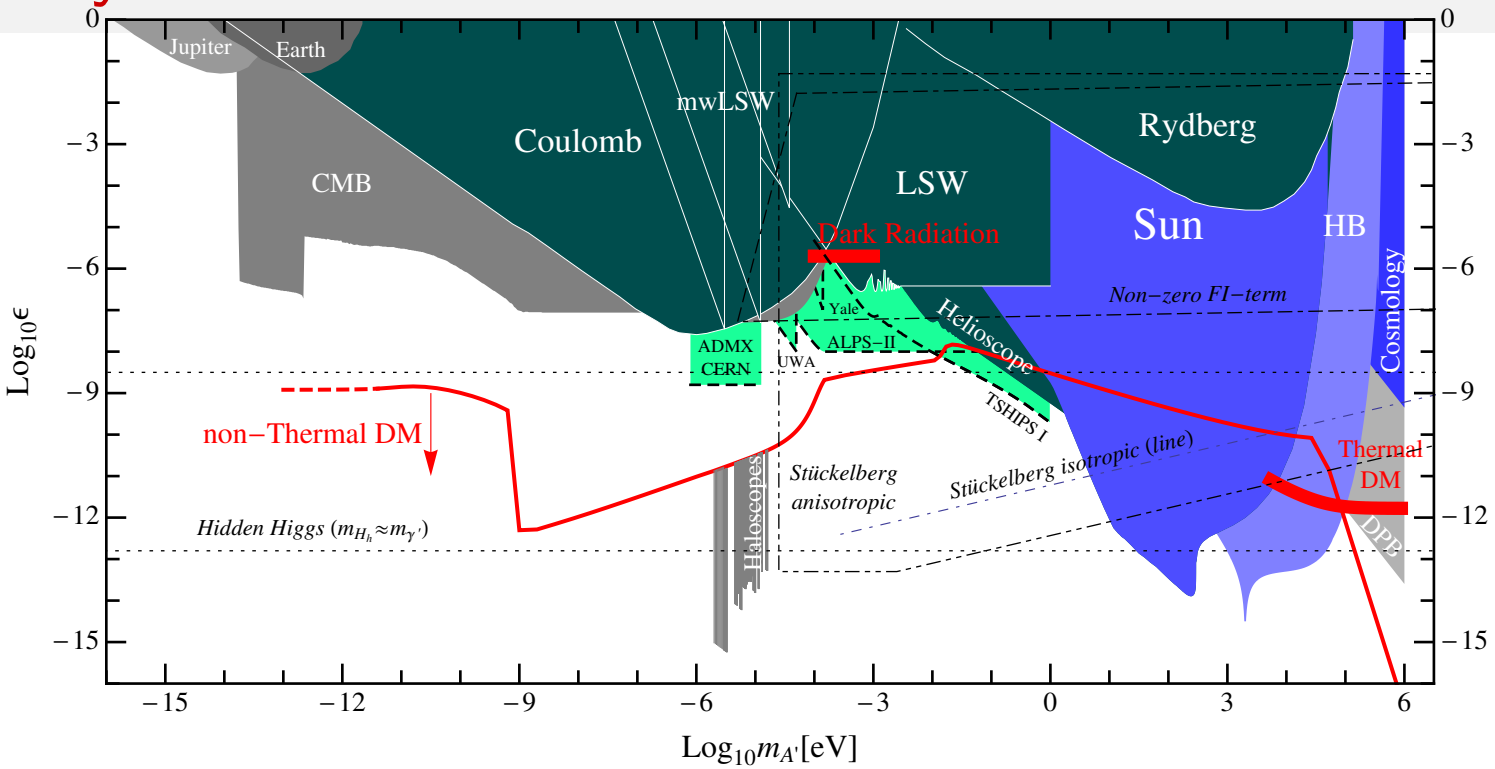
Next steps & on the longer run

get the optical done first!



- cooled Enterprise PMT 9107 with $\sim 1-3$Hz Dark noise delivered at 25mm active diameter
- detector is being characterized, shutter tested...
- Expect to cut into HP DM parameter space around 2-4 eV in few hours measurement only
- after that: check background & reflectivity at lower frequencies

Summary



- Hidden Photons very light-weight and very weakly coupled
- comparatively easy to check by small-scale, cheap, shots in the dark
- often interdisciplinary (GW, cosmic ray, accelerator...) & fun
- ALPS-II and FUNK results on Hidden photons (indirect and Dark Matter direct search) soon
- many efforts not mentioned, e.g. hidden photon radios...

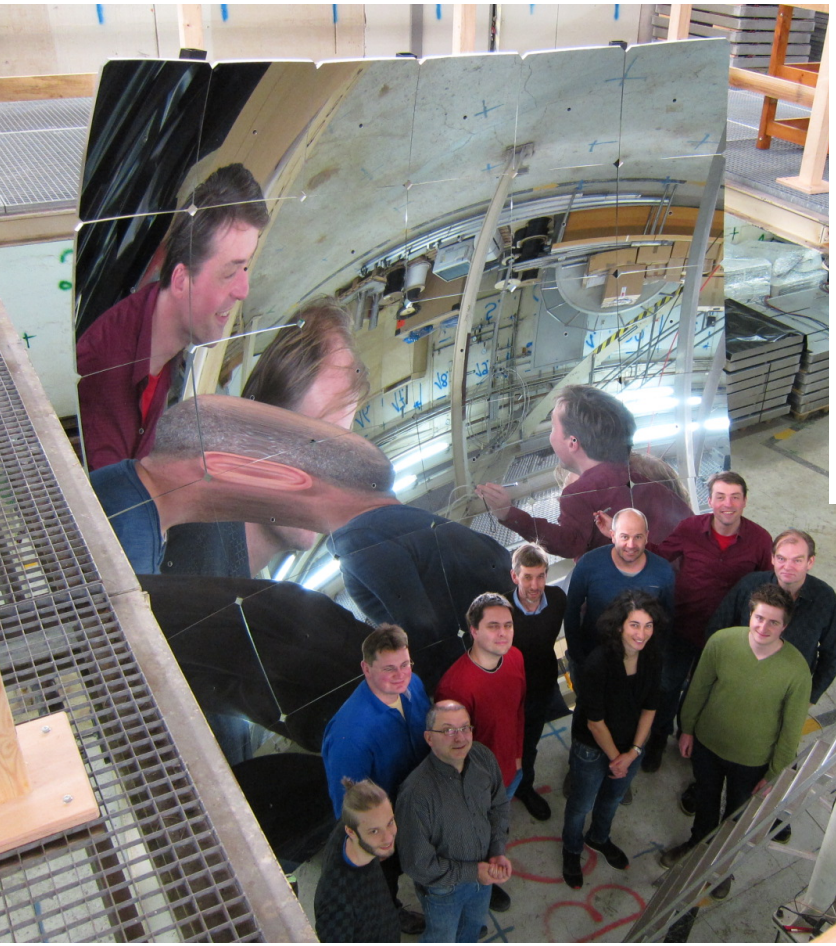
Thank you... and the people doing the work

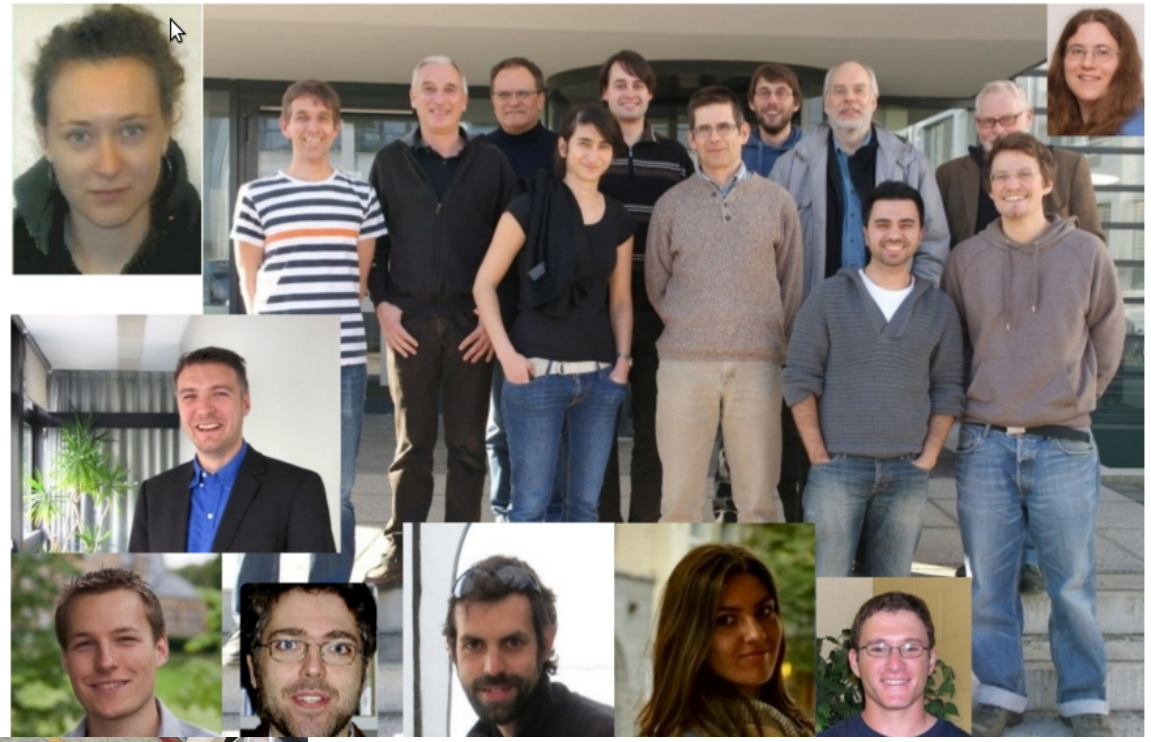
ALPS-II →

reading:

TDR JINST 1309, T09001

alps.desy.de





← FUNK

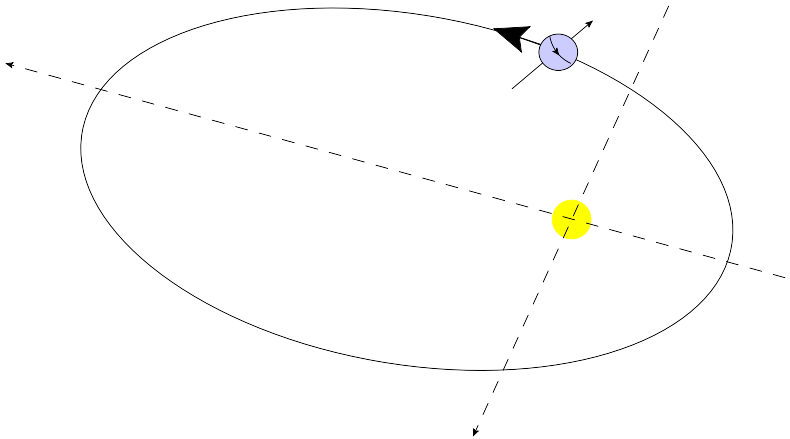
reading:

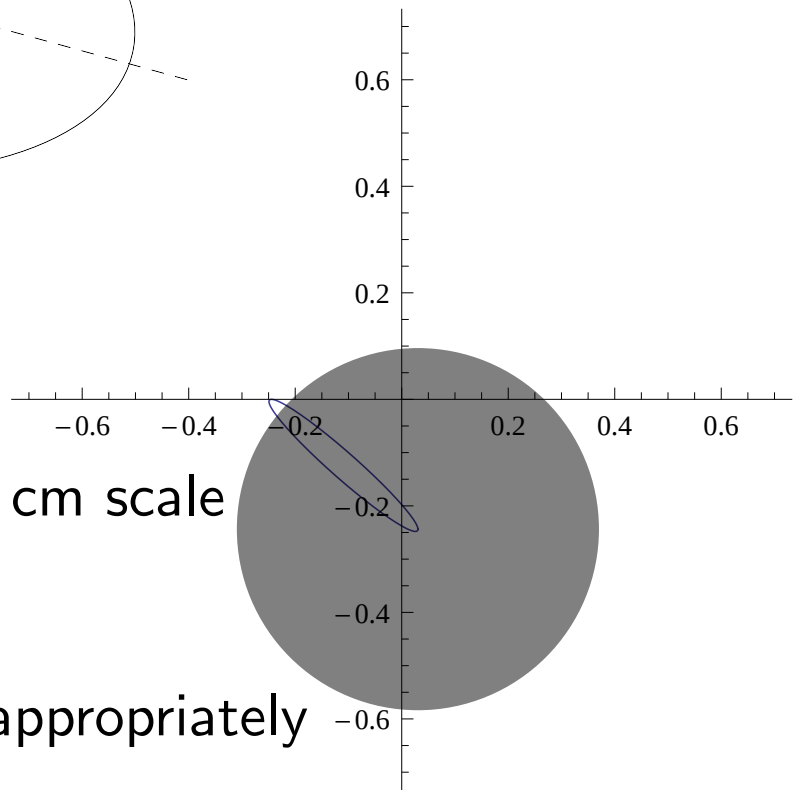
Proceedings: arXiv:1410.0200

Bachelor thesis Ch.Schäfer KIT

Directionality for $\lambda \ll$ dish scale general: Jae/Red, JCAP 1311 (2013) 016

DM @ 60° to ecliptic ↘





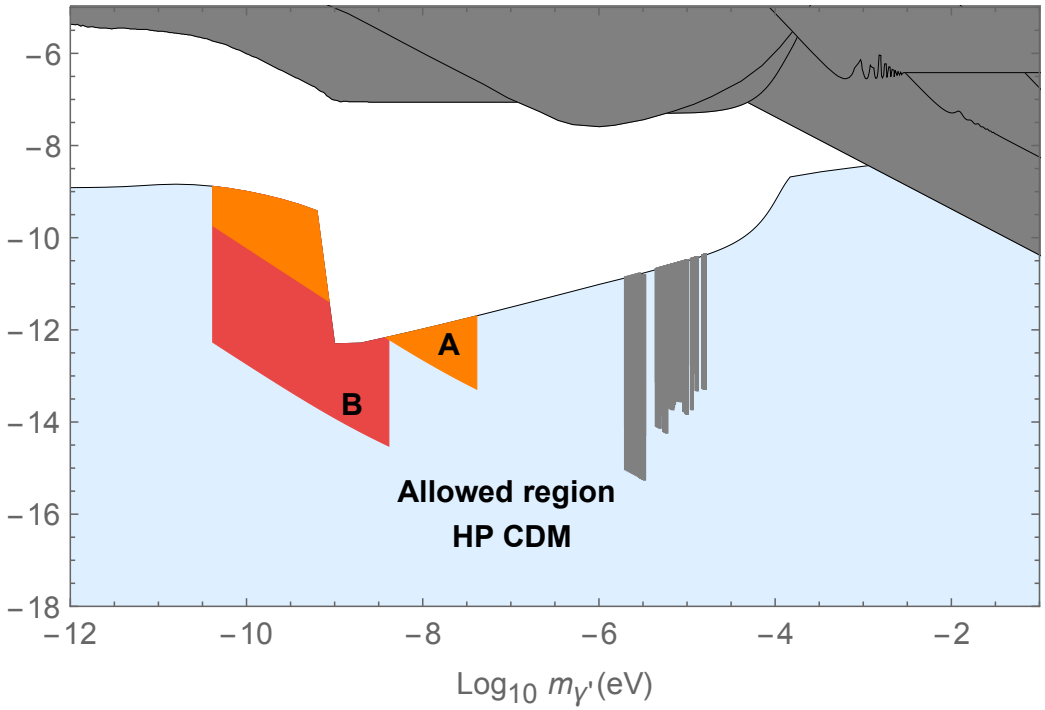
cm scale

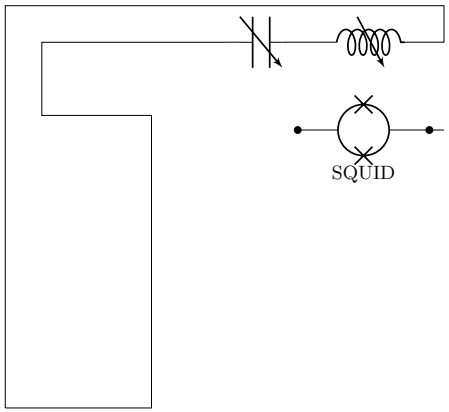
example R=3.4m

choose detector size appropriately

- spot-radius-**broadening** DM velocity distribution $\Delta d \sim 1\mathrm{mm}(\frac{R}{\mathrm{m}})$ (if $\Delta v \sim 10^{-3}$) +**movement** (in DM frame)
- point spread ∼ mm and daily mod ∼ mm, yearly mod negligible. dependent on exact orientation

Hidden photon LC circuit (radio, applicable for low m?)

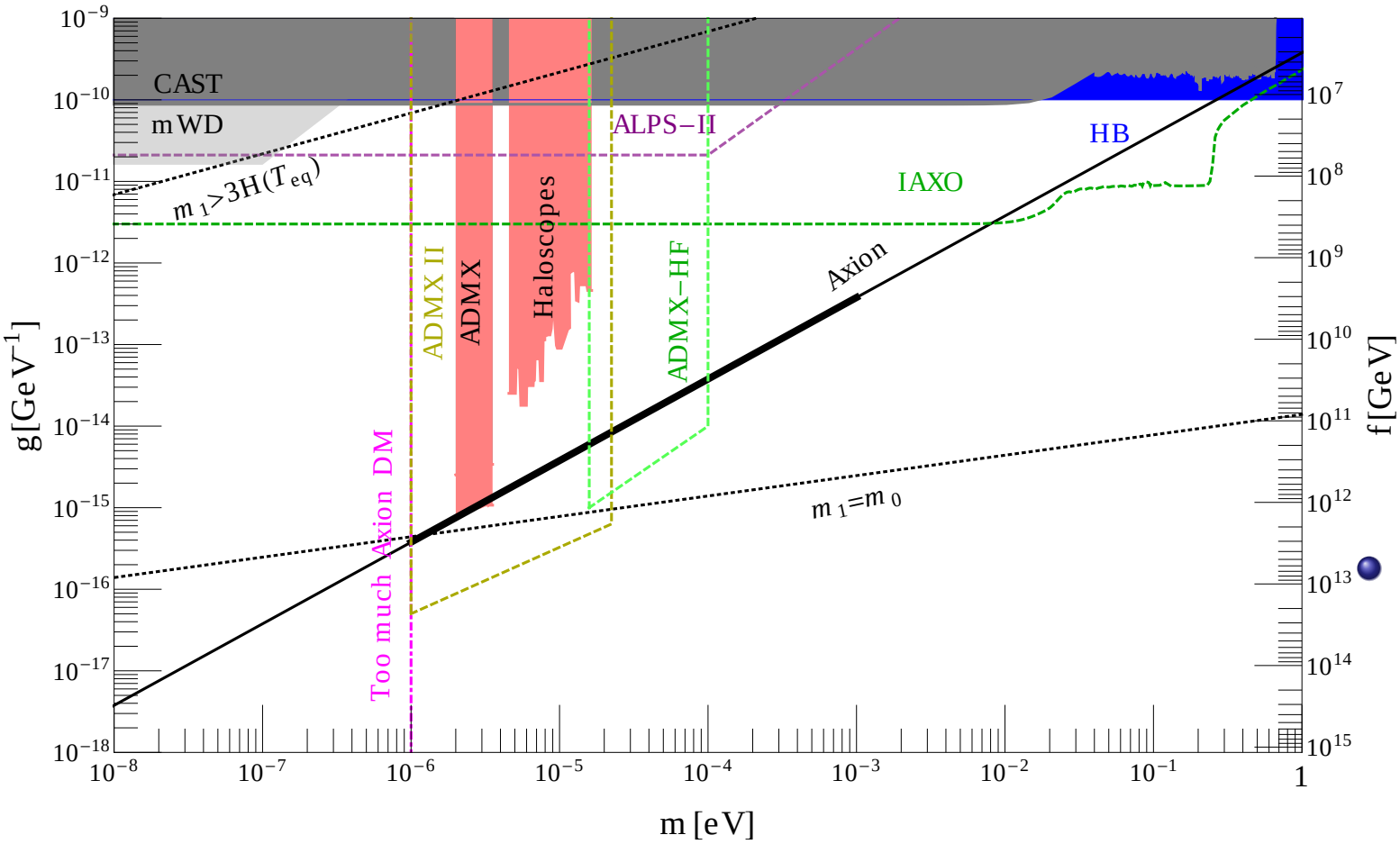




- HP DM inducing a current in a superconducting cryogenic, circuit idea for axions Sikivie et al Phys.Rev.Lett. 112 (2014) 13, 131301
- applicable also for HPs: Arias et al arxiv:1411.4986
- detailed studies of a 'hidden photon radio': Chaudhuri et al 1411.7382

Axions and Axion-like particles as DM

see, e.g.[1501.03274]



- Axions and ALPs $\mathcal{L}_{\text{int,PS}} \sim g_{\phi\gamma}\phi\, F_{\mu\nu}\tilde{F}^{\mu\nu}$ **QCD Axion**, m_a & g tied, coupling tiny
- (m, g)-plane: axion-*like* particles