Any Light Particle Search II

79. Physics Research Committee

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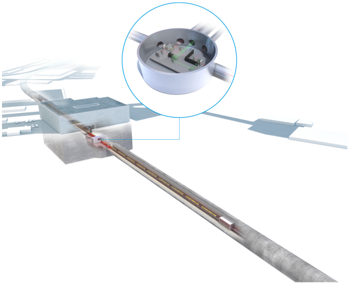
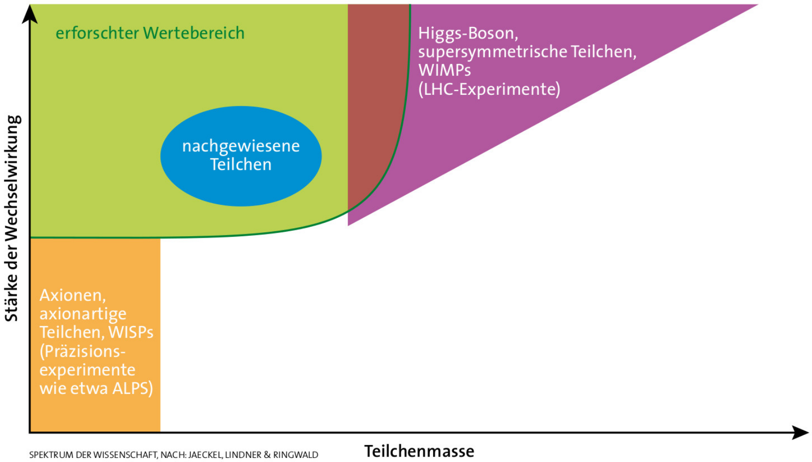
Spring 2015



Hidden Sector



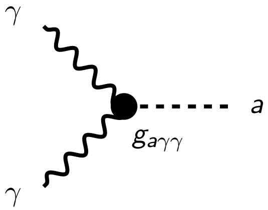
Weakly Interacting Sub-eV Particles

Axions / Axion-Like-Particles (ALPs)

- Axion introduced to solve **strong-CP problem** (1978)

$$\mathcal{L} \supset -\frac{\alpha_s}{8\pi}\,\theta\; G^a_{\mu\nu}\tilde{G}^{a,\mu\nu}$$

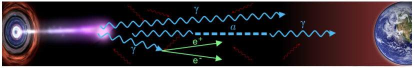
- Axions / ALPs arise **generically** in various BSM theories
- Candidates for **dark matter**
- Common feature:
  - **Effective photon coupling**



Weakly Interacting Sub-eV Particles

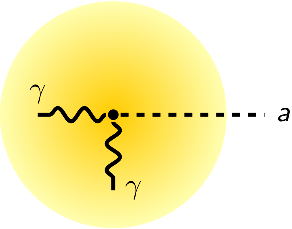
Hints to Axions / ALPs

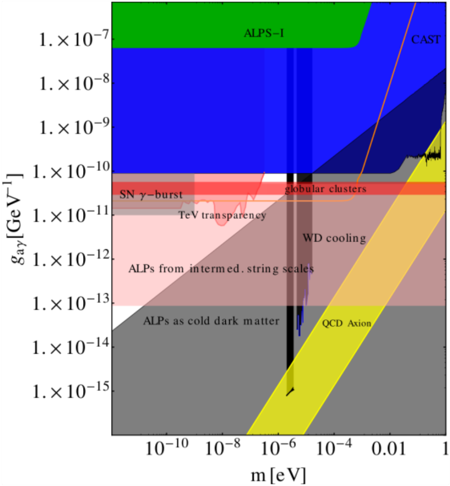
- Anomalous TeV-Transparency



[1201.4711]

- Globular Clusters *[1406.6053]*, White-Dwarf-Cooling *[1204.3565]*





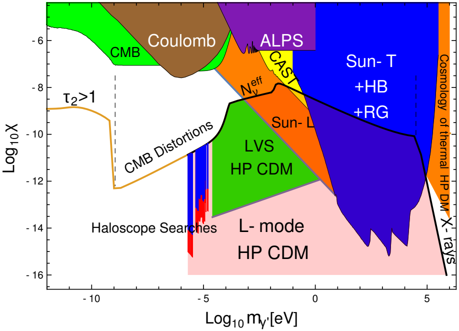
Weakly Interacting Sub-eV Particles

Hidden Photons

- Gauge boson of hidden local $U(1)$ symmetry
- **Kinetic Mixing** with SM-γ

- Quantum fluctuations during inflation allowing HP production
- Lower bound: *[1504.02102]*

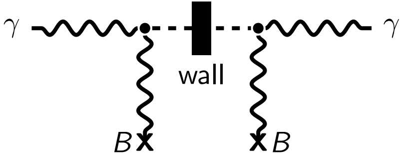
$$\frac{\rho_{\gamma'}}{\rho_{DM}} \gtrsim \left(\frac{m_{\gamma'}}{6\cdot 10^{-6}\,\mathrm{eV}}\right)^{1/2}\left(\frac{H_I}{10^{14}\,\mathrm{GeV}}\right)^2$$

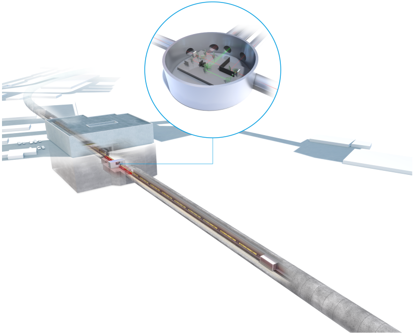


- ALPS II sensitivity:

$$\chi \gtrsim 2\cdot 10^{-9}$$
$$m_{\gamma'} \gtrsim 4\cdot 10^{-4}\,\mathrm{eV}$$

Light-Shining-Through-Wall



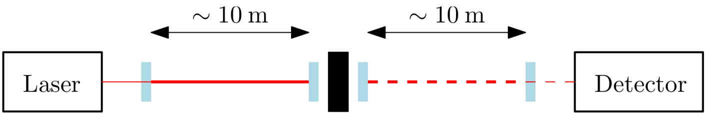


Conversion Probability for Axions / ALPs

$$P_{a\leftrightarrow\gamma} = 2.6\cdot 10^{-17}\left(\frac{B}{10\,\mathrm{T}}\right)^2\left(\frac{L}{10\,\mathrm{m}}\right)^2\left(\frac{g_{a\gamma\gamma}}{10^{-10}\,\mathrm{GeV}}\right)^2$$

ALPS II Sensitivity

Development Stage



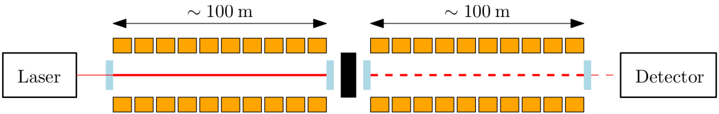
- **Production-Cavity:**
  - Power Buildup: $\beta_{\text{PC}} = 5000$
- **Regeneration-Cavity:**
  - Power Buildup: $\beta_{\text{RC}} = 40000$

$$\textit{sensitivity} \propto \left(\frac{1}{\beta_{PC} \cdot \beta_{RC}}\right)^{\frac{1}{4}}$$

Sensitivity Gain $(\mathrm{ALPS\text{-}I} \rightarrow \mathrm{II})$: $\times 3.5 \;\; \times 14$

ALPS II Sensitivity

Final Stage

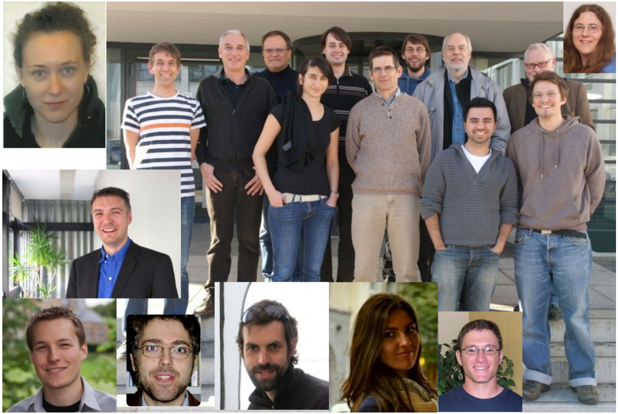


- **Magnetic Length:**
  - $(10 + 10)$ HERA dipoles
  - $BL = 468\,\mathrm{T\,m}$

$$\text{sensitivity} \propto \left(\frac{1}{BL}\right) \cdot \left(\frac{1}{\beta_{PC} \cdot \beta_{RC}}\right)^{\frac{1}{4}}$$

Sensitivity Gain $(\mathrm{ALPS\text{-}I} \to \mathrm{II})$: $\times 21$

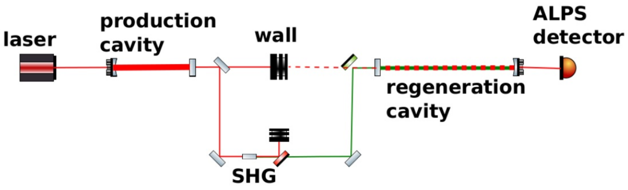
ALPS II Collaboration



. . . too busy to take an up-to-date picture

ALPS II: Optics

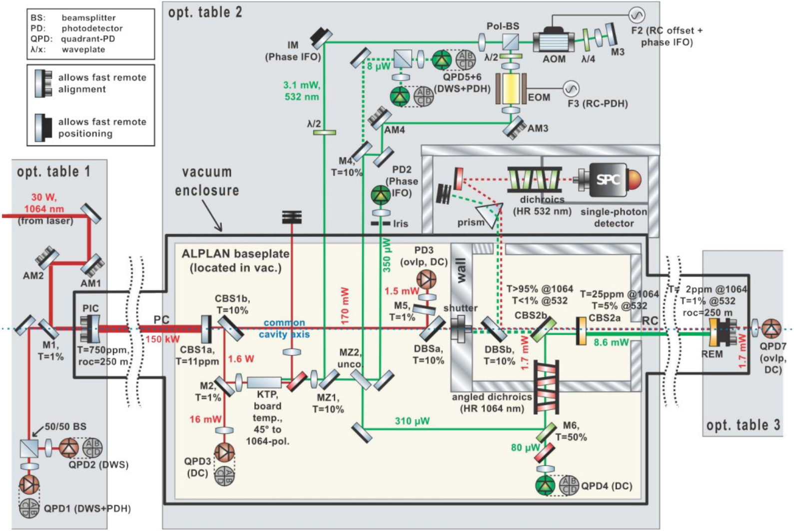
Conceptual design



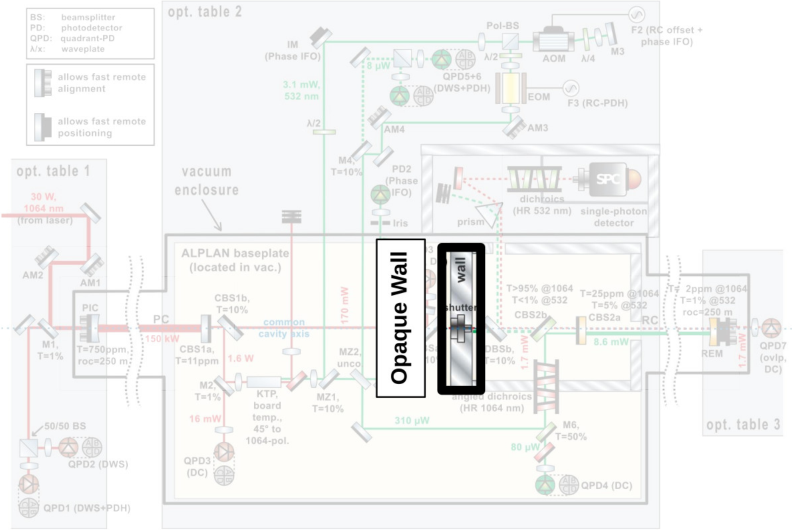
- Stabilize cavities
  - Pound-Drever-Hall
  - Differential-Wavefront-Sensing
- Keep regeneration cavity on resonance with green light
- overlap of cavity modes

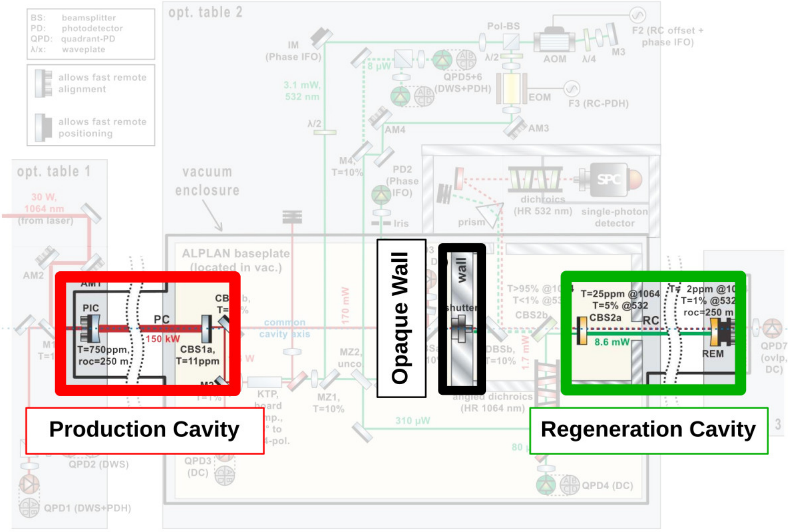
ALPs signal: reconverted red photons

ALPS II: Optics



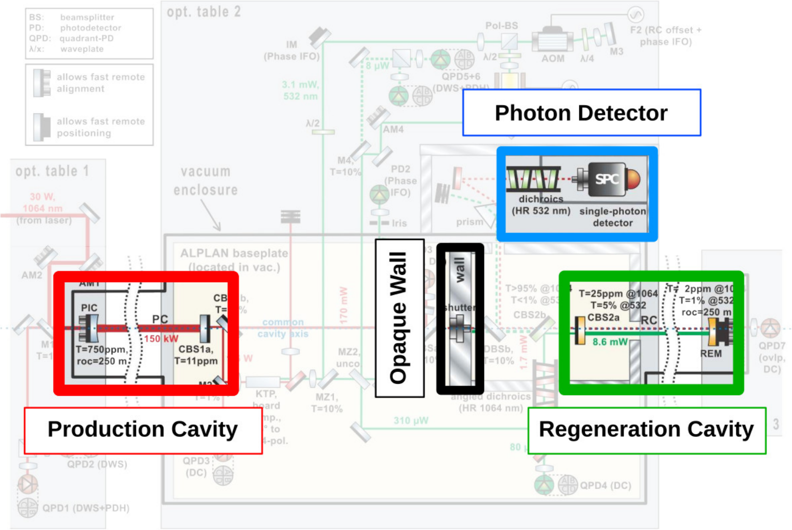
ALPS II: Optics





Production Cavity
Regeneration Cavity
Opaque Wall
wall
shutter
opt. table 1
opt. table 2
vacuum enclosure
ALPLAN baseplate (located in vac.)
BS: beamsplitter
PD: photodetector
QPD: quadrant-PD
λ/x: waveplate
allows fast remote alignment
allows fast remote positioning
PIC
PC
150 kW
T=750ppm, roc=250 m
CBS1a, T=11ppm
RC
REM
CBS2a
8.6 mW
T=25ppm @1064
T=5% @532
QPD1 (DWS+PDH)
QPD2 (DWS)
QPD3 (DC)
QPD4 (DC)
QPD5+6 (DWS+PDH)
Pol-BS
AOM
EOM
SPC
single-photon detector
dichroics (HR 532 nm)
angled dichroics (HR 1064 nm)
prism
Iris
310 μW

ALPS II: Optics

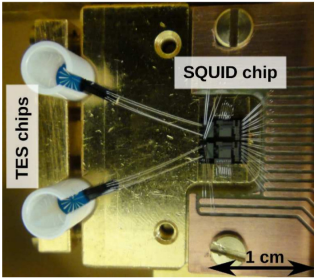


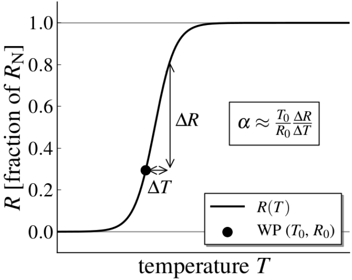
ALPS II: Detector

Transition Edge Sensor (TES)

- 25 µm × 25 µm Tungsten-Film
- Microcalorimeter operating at 80 mK

- Signal $\mathcal{O}$(70 nA) read via SQUID
- Intrinsic bkg. rate 10^{-4} Hz
- Energy resolution below 10%

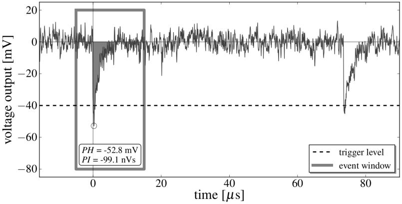




ALPS II: Detector

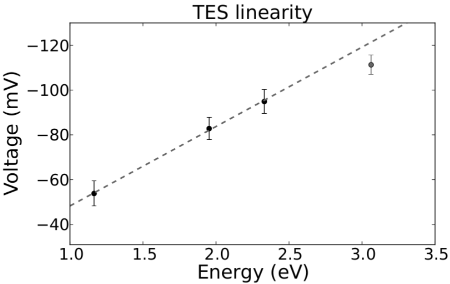
Performance

- Setting-up operation done!
- Performance paper published [1502.07878]
- Optimized detection efficiency measurement ongoing



Water circuit

- Heavy contamination lead to Long-Shutdown-1
- Improved (closed cycle) cooling circuit

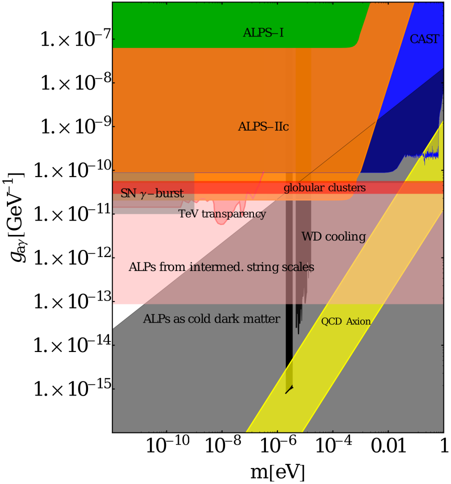


ALPS II: Magnets

Status & Procedure

- First **straightened** test magnet operated successfully
  - Even with $I > I_{\mathrm{design}}$
- **Second magnet** on test bench
- Successfully operated after 25 y in storage

Summary



- New aspect on physics case
  - Hidden Photons from inflation
- Lot of progress in all scopes
- ALPS IIa preparatory phase (hopefully) finished this year
  - setup / performance checks
- Physics Run (HP) in early 2016
- Continue setting up ALPS IIc

DESY
Physics Seminar

Searching for Dark-Matter Axions.

Leslie Rosenberg (Seattle)

Tuesday, 12 May 2015, 16:45 h, Auditorium

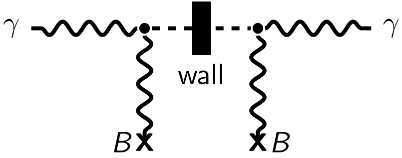
The axion is a hypothetical elementary particle whose existence would explain the baffling absence of CP violation in the strong interactions. Axions also happen to be a compelling dark-matter candidate. Even if dark-matter axions were to comprise the overwhelming majority of mass in the universe, they would be extraordinarily difficult to detect. However, several experiments, either under construction or taking data, would be sensitive to even the more pessimistically coupled axions.
This talk describes the current state of these searches.

Coffee, tea and cookies will be served at 16:30h.

After the seminar there is a chance for private discussions with the speaker over wine and pretzels.

BACKUP

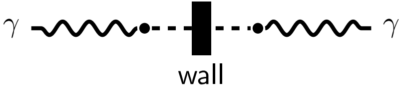
Conversion Probability for Axions/ALPs



$$P_{a\leftrightarrow\gamma} \;=\; \frac{1}{4}\, g_{a\gamma\gamma}^2\, (BL)^2\, \frac{\omega}{k_a}\, \frac{\sin^2\left(\frac{qL}{2}\right)}{\left(\frac{qL}{2}\right)^2}$$

$$k_a^2 = \omega^2 - m_a^2 \qquad\qquad q = n\omega - \sqrt{\omega^2 - m_a^2}$$

Conversion Probability for Hidden Photons



$$P_{\gamma \leftrightarrow \gamma'} \ = \ 4\chi^2 \frac{m_{\gamma'}^4}{M_{\gamma'}^4} \ \sin^2 \left(\frac{M_{\gamma'}^2 L}{4\omega} \right)^2$$

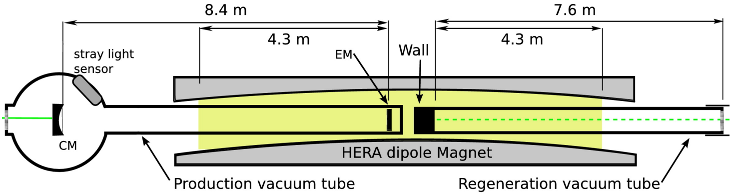
$$M_{\gamma'}^2 = (m_{\gamma'}^2 + 2\omega^2(n-1))$$

Sensitivity

$$S(g_{a\gamma\gamma}) \propto \frac{1}{BL}\left(\frac{DC}{t}\right)^{\frac{1}{8}}\left(\frac{1}{DE\cdot\beta_{PC}\cdot\beta_{RC}\cdot\dot{N}_{\text{prod}}}\right)^{\frac{1}{4}}$$

Parameter	Scaling	ALPS-I	ALPS-IIc	Sens. gain
Effective laser power P_{laser}	$g_{a\gamma} \propto P_{\text{laser}}^{-1/4}$	1 kW	150 kW	3.5
Rel. photon number flux n_γ	$g_{a\gamma} \propto n_\gamma^{-1/4}$	1 (532 nm)	2 (1064 nm)	1.2
Power built up in RC P_{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	$g_{a\gamma} \propto DC^{1/8}$	$0.0018\ \mathrm{s}^{-1}$	$0.000001\ \mathrm{s}^{-1}$	2.6
Combined improvements				3082

ALPS-I (2007–2010)



Specifications:

Magnet: 1× HERA dipole (8.83 m @ 5.3 T)

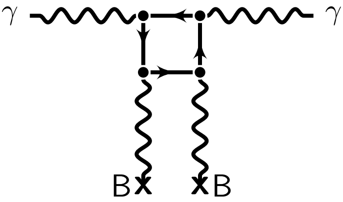
Laser: 5 W @ 532 nm CW

Detektor: PIXIS CCD @ −70 °C

Production Cavity

- Fabry-Pérot Resonator
- 1.2 kW circulating power

HERA-X



- **H**eisenberg
  Euler
  Bi**R**efringence
  ALPs
  e**X**periment

- Measure Ellipticity: $\Psi \propto B^2 L$

- Magnetic Length: $B^2 L \approx 2480\,\mathrm{T}^2\mathrm{m}$
  (PVLAS: $\approx 10\,\mathrm{T}^2\mathrm{m}$)

- **Pathfinder-Experiment starting soon**

  - New NPRO laser funded by SFB