Status of ALPS II at DESY

Jan Eike von Seggern for the ALPS collaboration

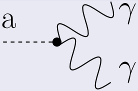
DESY Hamburg

7^{th} Patras Workshop
June, 30^{th} 2011

Weakly Interacting Slim Particles

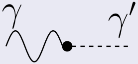
Axions and ALPs

- both share $\gamma\gamma a$-vertex
- only axions: $m_a/g_a \approx m_\pi f_\pi$

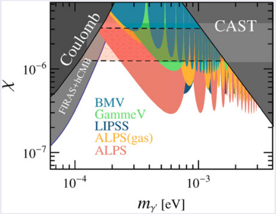


Hidden Photons

- Assume hidden $\mathrm{U(1)_h}$ (may result from string-theory)
- $\mathcal{L}_{\mathrm{eff}} \ni -\frac{1}{2}\chi\, F_{\mu\nu}\, B^{\mu\nu} \quad \Rightarrow \quad$ mixing $\gamma \leftrightarrow \gamma'$ (cf. neutrion oscillations)

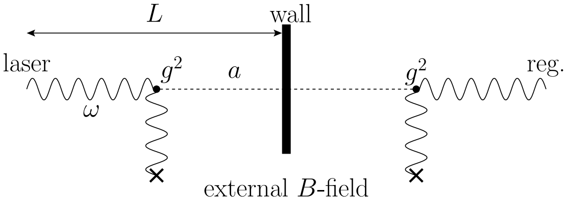


- Decoupling of HP in the early universe can explain WMAP-7 sterile neutrino ($N_\nu^{\mathrm{eff}} = 4.25\,^{+0.76}_{-0.80}$) result $\Rightarrow$ hCMB
  (J. Jaeckel, J. Redondo, A. Ringwald: PRL 101, 131801 (2008))



Light Shining through a Wall

- Illuminate a light tight wall and see what gets through
- measure light behind the wall
- use strong external B-field



- Conversion probability:

ALPs $\quad \mathcal{P}_{a\leftrightarrow\gamma} \propto g_a^2\,(B\,L)^2\; F\left(\frac{M^2 L}{\omega}\right)$

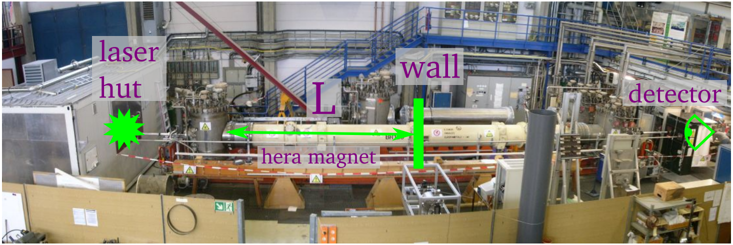
HP $\quad \mathcal{P}_{\gamma\leftrightarrow\gamma'} \propto g_{\gamma'}^2 \frac{m_{\gamma'}^4}{M^4} \sin^2 \frac{M^2 L}{4\omega} \xrightarrow[m_{\gamma'} \ll \omega]{\text{in vac.}} g_{\gamma'}^2 \frac{m_{\gamma'}^4 L^2}{(4\omega)^2}$

- we measure $\quad \mathcal{P}_{\rm prod} \cdot \mathcal{P}_{\rm reg} \sim g^4$

(for an overview see: J. Redondo and A. Ringwald: arXiv:1011.3741 [hep-ph])

ALPS I at DESY

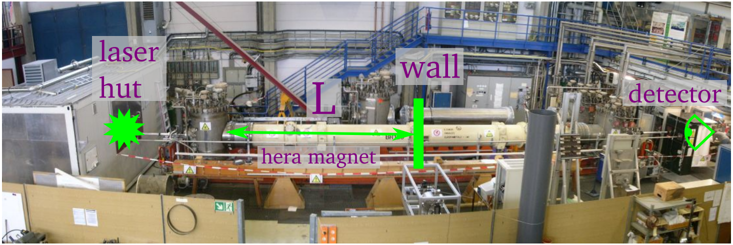
Any Light Particle Search



Laser

- Use IR laser from gravitational wave experiments
- Convert to green light with second harmonic generation (SHG) to make detection simpler
$$\rightarrow P = 5\,\mathrm{W}$$
- Increase number of photons in B-field with optical cavity
$$\rightarrow P = 1.2\,\mathrm{kW} \quad \hat{=} \quad 3.2 \times 10^{21}\,\mathrm{photons/s}$$

Any **L**ight **P**article **S**earch

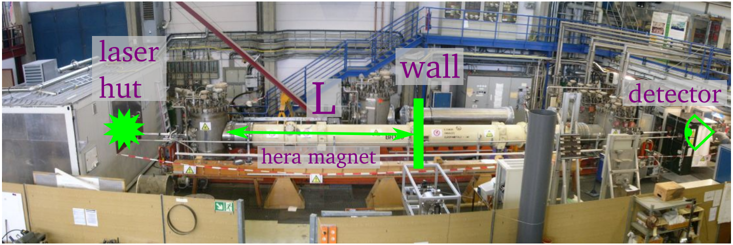


Magnet

- Use superconducting HERA magnet
- Field strength $B = 5\,\mathrm{T}$
- Length $L_{\mathrm{prod}} = L_{\mathrm{reg}} = 4.4\,\mathrm{m}$

ALPS I at DESY

Any **L**ight **P**article **S**earch



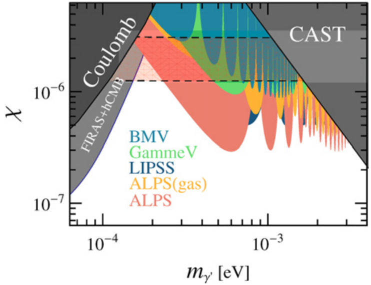
Detector

- Green light $\Rightarrow E_\gamma = 2.3\,\mathrm{eV} > E_{\mathrm{gap}}(\mathrm{Si}) = 1.1\,\mathrm{eV}$
- Use off-the-shelf Si-CCD
- Quantum efficiency $\mathrm{QE} = 96\,\%$
- Cooled to $-70\,^\circ\mathrm{C}$ $\Rightarrow$ low thermal noise
- Integration times of $1\,\mathrm{h}$ possible (optimization of RO-noise domination + minimal prob. for cosmics + large statistics)

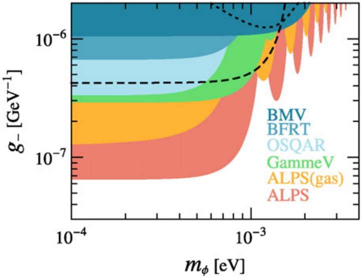
ALPS I – Results

- Finished data taking in 2009
- Comparison between background (laser off) and signal frames show no evidence for LSW
- but new upper limits

hidden photons:



axion-like particles:



(K. Ehret et al.: Physics Letters B 689 (2010) 149–155)

ALPS II – Plans

Increase sensitivity by

- More photons
- Increase probability for regeneration $a \to \gamma$
- Very-low-noise detector
- Stronger & longer magnets

remember:

$$\mathcal{P}_{a\leftrightarrow\gamma} \propto g_a^2 \, (B\,L)^2 \; F\left(\frac{M^2 L}{\omega}\right)$$

Laser & production cavity

- Old setup was limited by limited durability of cavity mirrors
- Switching to IR will allow for $P = 1.2\,\mathrm{kW} \to 150\,\mathrm{kW}$
- Improvement: ~ 4

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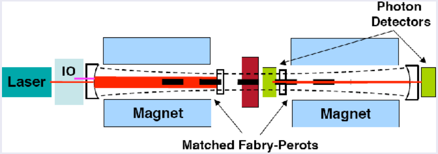
Regeneration cavity

- Implement an optical cavity on the regeneration side



(P. Sikivie. D. Tanner, K. van Bibber: PRL 98:172002, 2007)

- Coherent flux of virtual photons inside the cavity
- Planned power build-up $PB \approx 40\,000 \Rightarrow$ improvement ~ 14

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Detector

- Problem $E_\gamma(IR) = 1.2\,\mathrm{eV} \approx E_{\mathrm{gap}}(\mathrm{Si}) = 1.1\,\mathrm{eV}$
- Develop superconducting transition-edge sensor with almost zero noise (cf. talk by G. Cantatore: PATRAS 2011)
- But R&D has just started
- Evaluate Si-CCD for IR to be used in first data runs

ALPS II – Plans

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Magnets

- LHC magnets stay at CERN
- HERA dipole magnets are available with curved beam pipes
- first tests to straighten beam pipes were successful: increased horizontal apperture: $14\,\mathrm{mm} \to 50\,\mathrm{mm}$

$\Rightarrow$ not stronger but longer: $2 \times 4.4\,\mathrm{m} \to 2 \times 100\,\mathrm{m}$

ALPS II – Plans

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Comparison

Parameter	ALPS I	ALPS II	Sensitivity gain
laser power	$1\,\mathrm{kW}$	$150\,\mathrm{kW}$	3.5
magnets	$0.5 + 0.5$ HERA	$12 + 12$ HERA	24
reg. cavity power built-up	1	$40\,000$	14
total			1200

ALPS II – Plans

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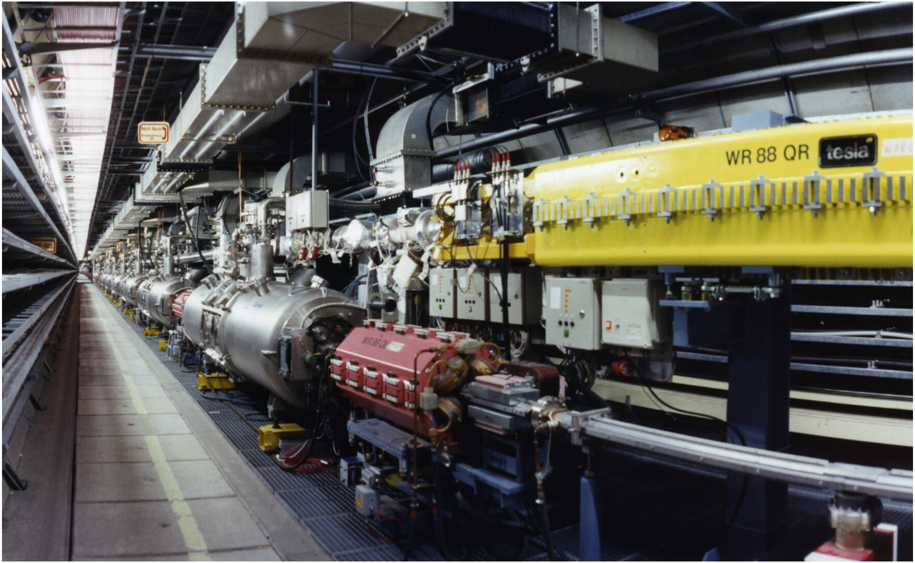
Timescale

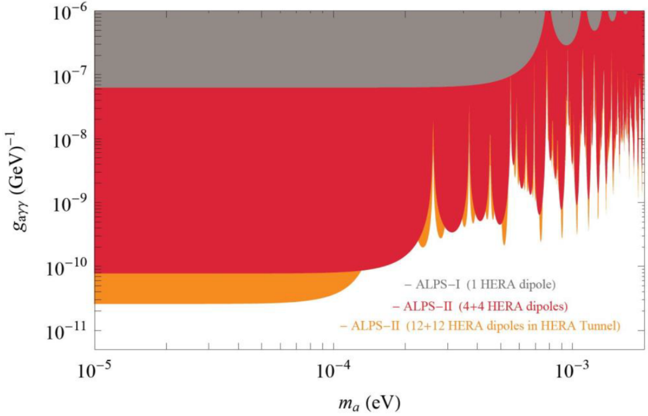
end 2012	$2 \times 10\,\mathrm{m}$ hidden photon search with stronger laser $\oplus$ regeneration cavity
end 2014	$2 \times 100\,\mathrm{m}$ hidden photon search in the HERA tunnel
$\sim$ 2017	axion-like particle search with 2×12 straight-ened HERA magnets

ALPS II – $2 \times 100\,\mathrm{m}$ in the HERA tunnel



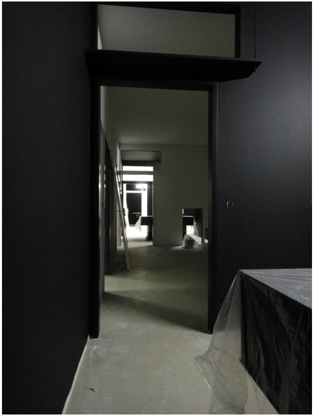
ALPS II – Sensitivity

axion like particles



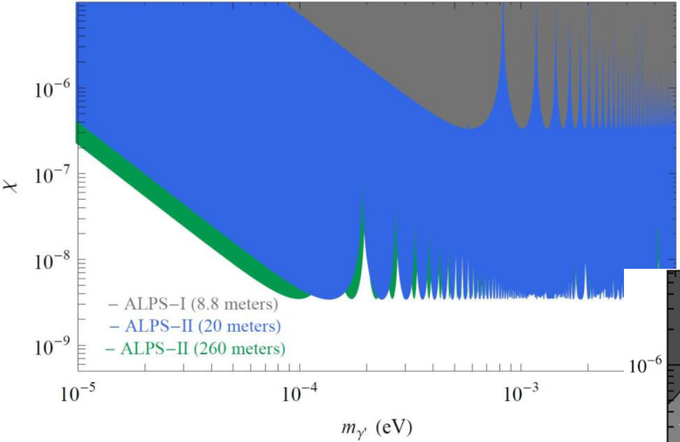
2009 ∼2017

New laser lab with three clean rooms under construction

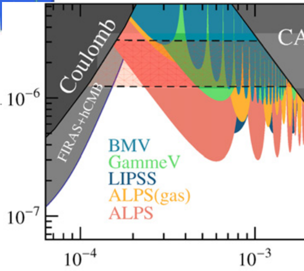


ALPS II – Sensitivity

hidden photons



2009 2012 2014



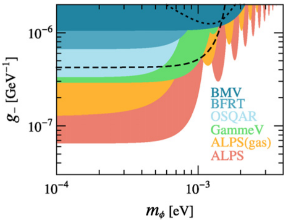
Conclusions

- The ALPS collaboration has grown considerably in preparation for ALPS II
- Joint TES development with Giovanni Cantatore
- The regeneration cavity will improve the sensitivity by one order of magnitude
- With the $2 \times 10\,\mathrm{m}$ proof-of-concept setup the hCMB region can be covered
- The overall sensitivity improvement will lead to $g \sim 2 \times 10^{-11}$
- Preparations for more than $200\,\mathrm{m}$ magnet string have started

Backup

$$\mathcal{P}_{a\leftrightarrow\gamma} \propto g_a^2\,(B\,L)^2\;F\left(\frac{M^2 L}{\omega}\right)$$

$$\propto g_a^2\,(B\,L)^2\;\underbrace{\sin^2\left(\frac{M^2 L}{4\omega}\right)\Big/\left(\frac{M^2 L}{4\omega}\right)^2}_{\to 1 \text{ for } M^2 \ll \omega/L}$$

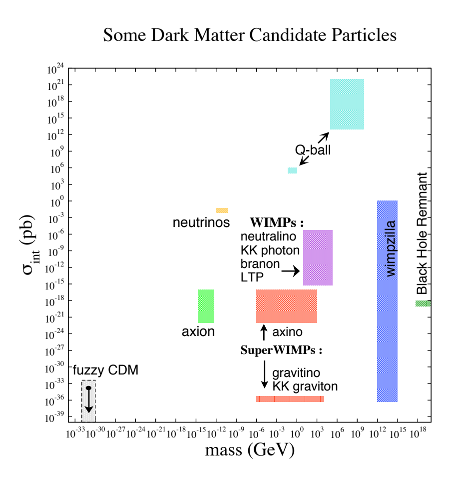


with B the field strength, L the field length, ω the photon energy and

$$M^2 = m_a^2 + 2\omega(n-1)$$

the quadratic sum of masses and g_a the coupling constant.

Some dark matter candidates: mass vs. interaction strength plane



(H. Baer: http://axion-wimp2009.desy.de/e30/e52240/e54378/HowieBaer.pdf)

The strong CP-Problem

- SM allows for **CP**-violating $\mathcal{L} \ni \bar{\theta}\frac{\alpha_s}{4\pi} G^b_{\mu\nu} \tilde{G}^{\mu\nu}_b$
- why are experimental limits $|\bar{\theta}| < 10^{-10}$ so small?

Solution (R.D. Peccei, H.R. Quinn, Phys. Rev. Lett. 38 (1977) 1440)

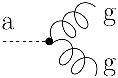
- Introduce new chiral symmetry: $U(1)_{\mathrm{PQ}}$
- SSB at scale f_a
- Add. terms in Lagrangian for Goldstone boson a:

$$\xi \frac{a}{f_a} \frac{\alpha_s}{4\pi} G^b_{\mu\nu} \tilde{G}^{\mu\nu}_b + \mathcal{L}_{\mathrm{kin}}[a] + \mathcal{L}_{\mathrm{int}}[\partial_\mu a]$$

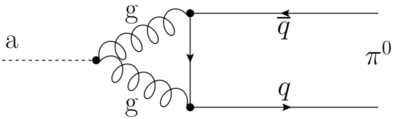
with VEV $\langle a \rangle = -\frac{f_a}{\xi}\bar{\theta}$

The Axion (I)

- Coupling to gluons:



- Axion-pion mixing:



$\Rightarrow$ axion-pion mass relation

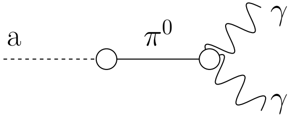
$$f_a\, m_a \simeq f_\pi\, m_\pi$$

- Direct couplings to fermions model dependent

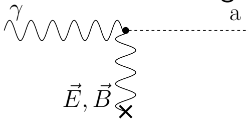
The Axion (II)

- Axion-pion mixing $\Rightarrow$ effective $a\gamma\gamma$-vertex:

  $\mathcal{L}_{\text{eff}} \ni -\frac{1}{4} g_{a\gamma\gamma}\, a\, F_{\mu\nu} \tilde{F}^{\mu\nu}$



- Possible axion production in strong $\vec{E}, \vec{B}$ fields :

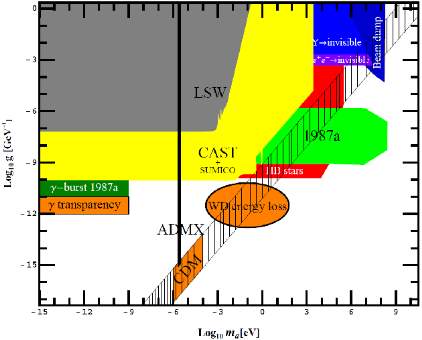


(Primakoff effect)

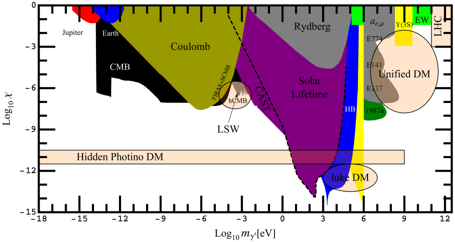
- Other extensions to the SM exist $\rightarrow$ axion-like particles (ALPs)
  - share the $a\gamma\gamma$ vertex
  - coupling and mass not connected with the pion

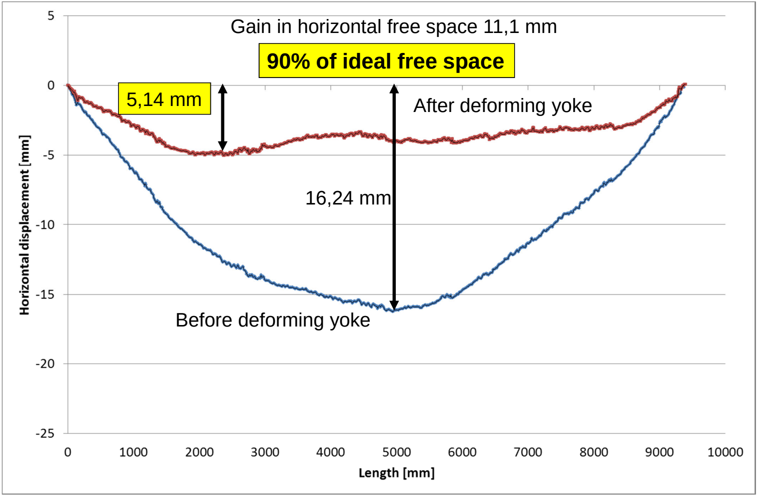
Limits and hints

ALPs



HP





(D.Trines: private communication)