Laboratory-based experiments probing lightweights from a dark sector

CERN, 15 August 2017
Axel Lindner
DESY
Outline

> Motivation for purely laboratory based efforts to find Weakly Interacting Slim Particles

> ALP / axion searches via photon couplings

> Light-shining-through-a-wall: ALPS II and beyond

> 5th force searches

> Summary
The dark sector could be complex with several constituents.

Dark matter does not need to consist of only one particle species.

To understand dark matter, any insight into the dark sector would be extremely helpful.

Are there bright spots for dark sector searches?

Weakly Interacting Slim Particles (WISPs) could explain the CP conservation of QCD and the vanishing EDM of the neutron:
An experimentalist’s motivation for WISP searches (1)

> **Weakly Interacting Slim Particles (WISPs)** could explain the CP conservation of QCD and the vanishing EDM of the neutron:

> **WISPs** may explain dark matter:

   - Axion
   - Axion-like particles
   - Hidden photons
   - …
WISP are hypothetical bosons with masses below 1eV (< 0,000002 m<sub>e</sub>).

Axion: a neutral pseudoscalar predicted to explain the CP conservation in QCD. Its physics is determined by a symmetry breaking scale f<sub>a</sub>:

- Mass: m<sub>a</sub> = 0.6eV · (10<sup>7</sup>GeV / f<sub>a</sub>)
- Coupling to two photons: g<sub>aγγ</sub> = α·g<sub>γ</sub> / (2π·f<sub>a</sub>)
- Abundancy in the universe: Ω<sub>a</sub> / Ω<sub>c</sub> ~ (f<sub>a</sub> / 10<sup>12</sup>GeV)<sup>7/6</sup>

Axion-like particles (ALPs):
Coupling strength and mass are not related by one f<sub>a</sub>.

Hidden photons: neutral vector bosons.

Mini-charged particles, Chameleons, massive gravity scalars, … (some of these might be related to dark energy).
A word on axions and axion-like-particles (ALPs)

Axion and other Nambu-Goldstone bosons arising from spontaneous breakdown of global symmetries are theoretically well-motivated very weakly interacting slim (ultra-light) particles. The coefficients are determined by specific ultraviolet extension of SM.

\[
\mathcal{L} \supset -\frac{\alpha_s}{8\pi} \frac{C_{a,g}}{f_a} a G^{b \mu \nu} \tilde{G}_{b,\mu \nu} - \frac{\alpha}{8\pi} \frac{C_{a,\gamma}}{f_a} a F_{\mu \nu} \tilde{F}^{\mu \nu} + \frac{1}{2} \frac{C_{a,f}}{f_a} \partial_\mu a \overline{\psi}_f \gamma^\mu \gamma^5 \psi_f
\]

Axio-electric effect
ALPs (axion & axion-like): what do we know?

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
ALPs (axion & axion-like): what do we know?

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.
Stellar developments:

- Extra energy loss beyond SM expectations is indicated by stellar developments.

- Such losses can be explained consistently by the emission of axions coupling to photons and electrons.


Anomalous transparency of the universe to TeV photons:

- TeV photons might not be absorbed in the intergalactic space due to $\gamma+\gamma \rightarrow e^+e^-$ scattering as predicted by QED.

- This could be explained by axion-like particles.

TeV photons in the universe might convert in magnetic fields to ALPs via their two-photon coupling.

Such ALPs might convert back to photons in the vicinity of earth.
Anomalous transparency of the universe to TeV photons:

- TeV photons might not be absorbed in the intergalactic space due to $\gamma+\gamma \rightarrow e^+e^-$ scattering as predicted by QED.

- This could be explained by axion-like particles.

TeV photons in the universe

“light-shining-through-the-wall” of extragalactic background light?
An an experimentalist‘s motivation for WISP searches (3)

Anomalous transparency of the universe to TeV photons:

- TeV photons might not be absorbed in the intergalactic space due to $\gamma+\gamma \rightarrow e^+e^-$ scattering as predicted by QED.

- This could be explained by axion-like particles.

A very similar axion-photon coupling as derived from stellar developments is required!


ALP couplings to explain an unexpected high transparency of the universe for TeV photons:

- **Hints for an axion-like particle from PKS 1222+216?**

- **Advantages of axion-like particles for the description of very-high-energy blazar spectra**

- **Sensitivity of the Cherenkov Telescope Array to the detection of axion-like particles at high gamma-ray opacities**

- **Towards discrimination between galactic and intergalactic axion-photon mixing**

- **Axion-like particles and the propagation of gamma rays over astronomical distances**
Motivation for purely laboratory based efforts to find Weakly Interacting Slim Particles

ALP / axion searches via photon couplings

Light-shining-through-a-wall: ALPS II and beyond

5th force searches

Summary
A word on axions and axion-like-particles (ALPs)

Axion and other Nambu-Goldstone bosons arising from spontaneous breakdown of global symmetries are theoretically well-motivated very weakly interacting slim (ultra-light) particles. The coefficients are determined by specific ultraviolet extension of SM.

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Courtesy A. Ringwald
Basis for experiments (works in both directions):

The polarization of light traversing a magnetic field is changed:

Only light polarized parallel (perpendicular) to the magnetic field couples to pseudoscalar (scalar) ALPs.

ALP searches via polarization effects

https://arxiv.org/abs/1510.08052

Very sensitive and model independent results, but

> going beyond CAST requires an increase in sensitivity by six orders of magnitude.

> This is hard to imagine and QED strikes back!
Observable effects from ALP-photon coupling (1)

Basis for experiments (works in both directions):

- Polarization in a magnetic field: QED background!

Photon splitting
Negligible, but hard to improve present experiments

Vacuum magnetic birefringence
Serious

Only light polarized parallel (perpendicular) to the magnetic field couples to pseudoscalar (scalar) ALPs.
Observable effects from ALP-photon coupling (2)

Basis for experiments (works in both directions):

> ALP-photon mixing in a magnetic field changes the refraction index …

... and causes a phase shift relative to a magnetic field free region.

With aLIGO sensitivities and long magnet strings QCD-axions are in reach, but …

Observable effects from ALP-photon coupling (2)

Basis for experiments (works in both directions):

> ALP-photon mixing in a magnetic field changes the refraction index …

… and causes a phase shift relative to a magnetic field free region.

With aLIGO sensitivities and a long magnet string QCD-axions are in reach, but … QED background is two orders of magnitude larger.
Observable effects from ALP-photon coupling (3)

- Polarization

- Interferometry

J. E. Kim et al., Rev. Mod. Phys. 82 (2010), 557-602
Finding ALPs in the lab: photon coupling options

- Polarization
- Interferometry
- Light-shining-through-a-wall

QED background!
Finding ALPs in the lab: photon coupling options

- **Polarization**

There are notable exceptions: searching for parity violating dark sector effects.

- **Interferometry**

- **Light-shining-through-a-wall**
How to look for ALPs …

… by exploiting their coupling to photons:

> ALPs pass any barrier and could make

light-shining-through-a-wall.

\[
\begin{align*}
P_{\gamma \to \phi}(B, \ell, q) &= \frac{1}{4} (g B \ell)^2 F(q\ell) \\
F(q\ell) &= \left[ \frac{\sin \left( \frac{1}{2} q \ell \right)}{\frac{1}{2} q \ell} \right]^2
\end{align*}
\]

\( q = p_\gamma - p_\phi \)

I: length of B field

How to look for ALPs …

… by exploiting their coupling to photons:

> ALPs pass any barrier and could make light-shining-through-a-wall.

$ql << 1$; conversion and re-conversion:

$$P_{\gamma \to \phi \to \gamma} = \frac{1}{16} \cdot (g_{a\gamma} Bl)^4 = 6 \cdot 10^{-38} \cdot \left( \frac{g_{a\gamma}}{10^{-10} \text{GeV}^{-1}} \cdot \frac{B}{1 \text{T}} \cdot \frac{l}{10 \text{m}} \right)^4$$

Three kinds of searches

> Purely laboratory experiments (“light-shining-through-walls”) optical photons,

> Helioscopes (WISPs emitted by the sun), X-rays,

> Haloscopes (looking for dark matter constituents), microwaves.
Three kinds of searches

- Purely laboratory experiments ("light-shining-through-walls") optical photons,

- Helioscopes (WISPs emitted by the sun), X-rays,

- Haloscopes (looking for dark matter constituents), microwaves.
Pros and cons for LSW in the laboratory

<table>
<thead>
<tr>
<th>ALP parameter</th>
<th>LSW (laboratory)</th>
<th>Helioscopes</th>
<th>Dark matter searches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parity and spin</td>
<td>yes</td>
<td>perhaps</td>
<td>yes</td>
</tr>
<tr>
<td>Coupling $g_{a\gamma}$</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Coupling $\cdot$ flux (does not apply)</td>
<td>(does not apply)</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Mass</td>
<td>perhaps</td>
<td>perhaps</td>
<td>yes</td>
</tr>
<tr>
<td>Rely on astrophysical assumptions</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>QCD axion</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

LSW in the laboratory is very well suited to look for axion-like particles to open up the window to the hidden sector.
Design criteria for LSW experiments with optical resonators

\[ P_{\gamma\to\phi\to\gamma} = \frac{1}{16} \cdot \mathcal{F}_{PC} \mathcal{F}_{RC} \cdot (g_{\alpha\gamma} B l)^4 = 6 \cdot 10^{-38} \cdot \mathcal{F}_{PC} \mathcal{F}_{RC} \cdot \left( \frac{g_{\alpha\gamma}}{10^{-10} \text{GeV}^{-1}} \frac{B}{1 \text{T}} \frac{l}{10 \text{m}} \right)^4 \]

- Use long strings of strong dipole magnets.
- Implement optical resonators to recycle the light before the wall and to boost the re-conversion of ALPs to photons behind the wall.
- The maximal length is given by the aperture of the magnets and the beam shape of the resonating mode in the optical resonators.
- The maximal circulating light power before the wall is given by the damage threshold of the mirrors and the beam spot size.

Courtesy A. Spector (ALPS)
Present and future dipole magnets for LSW experiments

LSW experiments use dipoles developed for particle accelerators (and might use in future dipole magnets presently under development).

> OSQAR: LHC dipoles.

> ALPS II: HERA dipoles.
Present and future dipole magnets for LSW experiments

LSW experiments use dipoles developed for particle accelerators (and might use in future dipole magnets presently under development).

- Thereafter one (or more) of these magnet designs may be produced in small series and become available for LSW experiments.
- Depending of unit length, some 30-40 units may be needed for a 500 m long magnet string.
Present and future dipole magnets for LSW experiments

LSW experiments use dipoles developed for particle accelerators (and might use in future dipole magnets presently under development).

<table>
<thead>
<tr>
<th>Dipole</th>
<th>Aperture [mm]</th>
<th>Field strength [T]</th>
<th>LSW experiment</th>
<th>Number of used dipoles</th>
</tr>
</thead>
<tbody>
<tr>
<td>HERA (straightened)</td>
<td>50</td>
<td>5.3</td>
<td>ALPS II (DESY)</td>
<td>20</td>
</tr>
<tr>
<td>LHC</td>
<td>40</td>
<td>9.0</td>
<td>OSQAR (CERN)</td>
<td>2</td>
</tr>
<tr>
<td>“FCC”</td>
<td>100</td>
<td>13</td>
<td>“ALPS III”</td>
<td></td>
</tr>
</tbody>
</table>

For the “FCC” dipole parameters see for example:


Optical resonators in LSW experiments

The resonators before and after the wall have to resonate to the same mode.

- Flat mirrors are placed in the center of the experiment around the wall.
- The light power density is highest on the flat mirror before the wall (mirror damage threshold)!
A confocal cavity:

- longest resonator for a given aperture,
- largest beamspot in the center and hence lowest power density on central mirror, therefore highest circulating power in the resonator before the wall.

https://en.wikipedia.org/wiki/Optical_cavity
Gaussian beam in a confocal resonator

Using:

- \( L \): length of the optical system, length of each resonator \( L/2 \).
- \( \lambda \): wavelength of light

> Beam waist: \( (\omega_0)^2 = (L \cdot \lambda) / 2\pi \)

> Beam profile development:

\[
\omega^2(z) = (\omega_0)^2 \cdot (1 + (z/z_R)^2),
\]
\[
z_R = \pi (\omega_0)^2 / \lambda
\]
\[
\omega(L/2) = \sqrt{2} \cdot \omega_0
\]

> Clear aperture required for a cavity with a power built-up \( \approx 100,000 \):

\[
r_5 = 2.5 \cdot \omega(z)
\]

https://en.wikipedia.org/wiki/Gaussian_beam
Optics for LSW experiments II: resonator examples

<table>
<thead>
<tr>
<th>Aperture [mm]</th>
<th>Safety margin [mm]</th>
<th>Eff. aperture [mm]</th>
<th>ω (L/2) [mm]</th>
<th>ω₀ [mm]</th>
<th>λ [nm]</th>
<th>L [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 (LHC)</td>
<td>10</td>
<td>30</td>
<td>6.0</td>
<td>4.2</td>
<td>1064</td>
<td>106</td>
</tr>
<tr>
<td>50 (HERA)</td>
<td>10</td>
<td>40</td>
<td>8.0</td>
<td>5.7</td>
<td>1064</td>
<td>189</td>
</tr>
<tr>
<td>100 (FCC)</td>
<td>10</td>
<td>90</td>
<td>18.0</td>
<td>12.7</td>
<td>1064</td>
<td>957</td>
</tr>
</tbody>
</table>

> λ = 1064 nm is assumed following LIGO experience: mirror coatings for this wavelength can stand high power densities for long times.
Optics for LSW experiments II: resonator examples

<table>
<thead>
<tr>
<th>Aperture [mm]</th>
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<th>Eff. aperture [mm]</th>
<th>( \omega (L/2) ) [mm]</th>
<th>( \omega_0 ) [mm]</th>
<th>( \lambda ) [nm]</th>
<th>L [m]</th>
<th>Maximal power [kW]</th>
<th>Magnetic length, one string [m]</th>
</tr>
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<tbody>
<tr>
<td>40 (LHC)</td>
<td>10</td>
<td>30</td>
<td>6.0</td>
<td>4.2</td>
<td>1064</td>
<td>106</td>
<td>280</td>
<td>43</td>
</tr>
<tr>
<td>50 (HERA)</td>
<td>10</td>
<td>40</td>
<td>8.0</td>
<td>5.7</td>
<td>1064</td>
<td>189</td>
<td>500</td>
<td>81</td>
</tr>
<tr>
<td>100 (FCC)</td>
<td>10</td>
<td>90</td>
<td>18.0</td>
<td>12.7</td>
<td>1064</td>
<td>957</td>
<td>2500</td>
<td>426</td>
</tr>
</tbody>
</table>

> \( \lambda = 1064 \) nm is assumed following LIGO experiences: mirror coatings for this wavelength can stand high power densities for long times.

> For the maximal power assume a damage threshold of 500 kW/cm\(^2\).

> For the magnetic length

- subtract 10 m for the optical system outside the magnets and
- assume a “filling factor” for the magnetic field of 90%.
Optics for LSW experiments III: 532 nm options

<table>
<thead>
<tr>
<th>Aperture [mm]</th>
<th>Safety margin [mm]</th>
<th>Eff. aperture [mm]</th>
<th>ω (L/2) [mm]</th>
<th>ω₀ [mm]</th>
<th>λ [nm]</th>
<th>L [m]</th>
<th>Maximal power [kW]</th>
<th>Magnetic length, one string [m]</th>
</tr>
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<tbody>
<tr>
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<td>12.7</td>
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<td>957</td>
<td>2500</td>
<td>426</td>
</tr>
<tr>
<td>50 (HERA)</td>
<td>10</td>
<td>40</td>
<td>8.0</td>
<td>5.7</td>
<td>532</td>
<td>378</td>
<td>?</td>
<td>166</td>
</tr>
<tr>
<td>100 (FCC)</td>
<td>10</td>
<td>90</td>
<td>18.0</td>
<td>12.7</td>
<td>532</td>
<td>1913</td>
<td>? · 5</td>
<td>856</td>
</tr>
</tbody>
</table>

> If high power, high quality mirror coatings for λ = 532 nm were available, LSW experiments could be doubled in length compared to λ = 1064 nm.

> R&D is required to improve the power density damage threshold of coatings for 532 nm light.
Challenges in optics

> Minimal losses: key parameter for the regeneration cavity!

ALPS II at DESY is “cutting edge” optics.

 Courtesy J. Põld, A. Spector (ALPS II)

plot from LIGO T-1400226-v6
Three main regions of interest:

> **Axion-like particles**: “new physics” around $10^5$ TeV.

> **QCD axions**: “new physics” around $10^5$ TeV.

> **QCD axions as dark matter**: “new physics” around $10^9$ TeV.

Stellar develop., TeV transp.
A LSW roadmap: Axions and axion-like-particles (ALPs)

- Improve on the ALPS-photon-photon coupling strength $g$ by > 1,000.

The experiment measures a rate $\sim g^4$:

- The experimental sensitivity is to increased by a factor $10^{12}$!
Motivation for purely laboratory based efforts to find Weakly Interacting Slim Particles

ALP / axion searches via photon couplings

Light-shining-through-a-wall: ALPS II and beyond

5th force searches

Summary
**AnyLightParticleSearch (ALPS) @ DESY in Hamburg**

*AnyLightParticleSearch (ALPS) @ DESY in Hamburg*
ALPS I:
approved 2007,
concluded 2010.
ALPS I: approved 2007, concluded 2010, most sensitive WISP search experiment in the lab (up to 2014).

ALPS II: targeting mainly axion-like particles, proposed 2011, TDR finished and evaluated in 2012.

Decision by the directorate: continue with the preparatory phase towards ALPS II.
ALPS II is realized in stages (JINST 8 (2013) T09001)

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
ALPS II is realized in stages (JINST 8 (2013) T09001)

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

ALPS IIa

The optics concept was invented three times independently:
ALPS II is realized in stages (JINST 8 (2013) T09001)

ALPS I

> ALPS IIa

> ALPS IIc

20 HERA dipoles, 200 m long
ALPS II optics: two mode-matched optical cavities

Production cavity, infrared

Wall

Regeneraton cavity, locked with green light.
ALPS II optics: two mode-matched optical cavities

Production cavity, infrared

with green light.
The central optics

Axel Lindner | Lab experiments | Dark sector and general relativity | CERN, August 2017 | Page 52
## ALPS II: optics

![Image](image_url)

### Characterization of optical systems for the ALPS II experiment

**Aaron D. Spector,**1,* Jan H. Pöld,2 Robin Bähre,3,4 Axel Lindner,2 and Benno Wilke 3,4

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*aron.spector@desy.de

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Goal</th>
<th>Achieved</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power-built up PC</td>
<td>5,000</td>
<td>4,000</td>
<td>Extra losses 77 ppm</td>
</tr>
<tr>
<td>Power in PC</td>
<td>150 kW</td>
<td>50 kW</td>
<td>Thermal effects on mirrors</td>
</tr>
<tr>
<td>Power-built up RC</td>
<td>40,000</td>
<td>14,000</td>
<td>Extra losses 55 ppm</td>
</tr>
<tr>
<td>Mirror alignment</td>
<td>5 μrad</td>
<td>&lt; 1 μrad</td>
<td></td>
</tr>
<tr>
<td>PC-RC spat. overlap</td>
<td>&gt; 95%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RC length stabilization</td>
<td>&lt; 0.5 pm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RC dual color lock</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Two ALPS II detector options (to convince everyone …)

> Transition Edge Sensor (TES) for photon counting:

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

> Heterodyne detection scheme:
mix light from ALPs with light at a slightly shifted frequency and look for a signal at the beat frequency.
## ALPS II schedule (rough)

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALPS IIa</td>
<td></td>
<td></td>
<td>(without magnets)</td>
<td></td>
<td>Install.</td>
</tr>
<tr>
<td>risk assessments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Runs</td>
</tr>
<tr>
<td>ALPS IIc</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

ALPS IIa today

ALPS IIc in 2019 in the HERA tunnel
The ALPS II collaboration

ALPS II is a joint effort of

> DESY,

> AEI Hannover
  (MPG & Hannover Uni.),

> Mainz University,

> University of Florida
  (Gainesville)

with strong support from

> neoLASE, PTB Berlin,
  NIST (Boulder).
ALPS II sensitivity

- Well beyond current limits.
- Aim for data taking in 2020.
- QCD axions not in reach.
- Able to probe hints from astrophysics.
- Need IAXO or “ALPS III” to fully exclude the ALP-explanation of the astrophysics hints.

ALPS II: $O(2 \text{ M}\$)
IAXO: $O(60 \text{ M}\$)
Excursus: the International Axion Observatory

> IAXO is proposed by scientists out of 38 institutes from 9 countries.

- CAST principle with dramatically enlarging the aperture
- Use of toroid magnet similar to ATLAS @ LHC
- X-ray optics similar to satellite experiments.

Conceptual Design of the International Axion Observatory (IAXO): JINST 9 (2014) T05002

IAXO "founding" meeting at DESY, July 2017: https://indico.cern.ch/event/622974/overview
Excursus: the International Axion Observatory

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  - CAST principle with dramatically enlarging the aperture
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Courtesy U. Scheekloth, DESY
Future lessons to be learned from ALPS II

- The optics and detector design should be ready by the end of 2018.
- At present we are optimistic to reach (or come close) to our specs.
- Most likely the performance will be “budget limited”.
- We should know in late 2018 how one could further improve if the available budget increases from \( \text{O}(1 \text{ M€}) \) to \( \text{O}(10 \text{ M€}) \).

ALPS II could show the path to “ultimate optics and detector concepts” for laser driven LSW experiments.

But new magnets are required for further jumps in sensitivity!
Ingredients for an “ALPS III” experiment

An “ALPS III” sketch:

- Magnetic field strength: 13 T ("FCC")
- Magnetic length: 426 m
- Light wavelength: 1064 nm ("standard")
- Circulating light power: 2.5 MW
- Photons against the wall: $1.4 \cdot 10^{25}$ s\(^{-1}\)
- Power built-up behind the wall: $10^5$
- Detector sensitivity: $10^{-4}$ s\(^{-1}\) ("demonstrated")
Ingredients for an “ALPS III” experiment

An “ALPS III” sketch:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Value</th>
<th>Sensitivity Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic field strength:</td>
<td>13 T</td>
<td>2.5</td>
</tr>
<tr>
<td>Magnetic length:</td>
<td>426 m</td>
<td>4.8</td>
</tr>
<tr>
<td>Light wavelength:</td>
<td>1064 nm</td>
<td></td>
</tr>
<tr>
<td>Circulating light power:</td>
<td>2.5 MW</td>
<td>2.0</td>
</tr>
<tr>
<td>Photons against the wall:</td>
<td>$1.4 \cdot 10^{25}$ s$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>Power built-up behind the wall:</td>
<td>$10^5$</td>
<td>1.3</td>
</tr>
<tr>
<td>Detector sensitivity:</td>
<td>$10^{-4}$ s$^{-1}$</td>
<td>1.0</td>
</tr>
</tbody>
</table>

> Improving the sensitivity for $g_{\alpha\gamma}$ compared to ALPS II by $2.5 \cdot 4.8 \cdot 2.0 \cdot 1.3 \cdot 1.0 = 30$
“ALPS III” in context

“ALPS III”

- would dramatically increase the sensitivity for purely laboratory based experiments searching for axion-like particles.
- would surpass even IAXO for very low mass ALPs.
- would definitely probe astrophysics hints for ALPs.
- would probe “dark matter” ALPs.
- would perfectly complement IAXO!
A little bonus

Assume to realize both magnet strings out of 40 dipoles each and

> switch polarity between each dipole (“wiggler configuration”):

The full sensitivity is restored at a specific mass!
Just for the fun of it: a little QCD axion bonus …

“ALPS III”

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Motivation for purely laboratory based efforts to find Weakly Interacting Slim Particles

- ALP / axion searches via photon couplings
- Light-shining-through-a-wall: ALPS II and beyond
- 5th force searches
- Summary
Fifth force mediated by ALPs / axions?

The coupling to nucleons and / or fermions could result in a fifth force:

- Look for spin-dependent forces.
- Range given by the axion mass \( \lambda_a = \frac{\hbar c}{m_a} \).

The challenge:

- Need to increase the sensitivity of existing experiments by eight orders of magnitude to access axions in the mass range \( 10^{-6} \) to \( 10^{-3} \) eV (100 \( \mu \)m to 10 cm).

Resonant detection of axion mediated forces with Nuclear Magnetic Resonance

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(Dated: March 7, 2014)

Fifth force mediated by ALPs / axions?

**Axion Resonant InterAction Detection Experiment (ARIADNE)**

> Under preparation at CAPP (Korea).

Rotating source mass induces an effective magnetic field $B_{\text{eff}}$.

**NMR sample ($^3$He)** tuned to the resonance frequency by $B_{\text{ext}}$.

Superconducting shielding

> If in resonance, the NMR sample will build up a magnetization perpendicular to its polarization:

$$M(t) \approx \frac{\hbar}{2} n_s p \mu_N \gamma_N B_{\text{eff}} t \cos(\omega t)$$
Fifth force mediated by ALPs / axions?

Axion Resonant Interaction Detection Experiment (ARIADNE)

> Under preparation at CAPP (Korea).

**Experimental parameters**

- 11 segments
- 100 Hz nuclear spin precession frequency
- $2 \times 10^{21}$ / cc $^3$He density
- 10 mm x 3 mm x 150 µm volume
- Separation 200 µm
- Tungsten source mass (high nucleon density)

A. Geraci
Fifth force mediated by ALPs / axions?

Axion Resonant Interaction Detection Experiment (ARIADNE)

Monopole-dipole interaction with $^3$He nuclei

Dipole-dipole interaction with $^3$He nuclei

QCD axions in reach, if CP violating interaction close to present limits from neutron EDM.

Requires a spin-polarized source mass. Less model dependent, but hard to reach the QCD axion. Look for other targets?

$m_a = 0.6 \text{meV} / (f_a/10^{10} \text{GeV})$
Summary

- Purely laboratory based experiments probe the hidden sector without relying on astrophysical and cosmological assumptions.

- “Light-shining-through-a-wall” will be able to probe for ALP-photon couplings as suggested by astrophysics hints.

- Spin-related 5th force experiments might reach the axion (model dependent).

- Do not forget about EDM searches.

- Future purely laboratory experiments deserve (and require) considerable effort!