ALPs: light-shining-through-walls with JURA

Annual Workshop
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Brief scientific motivation

Light-shining-through-walls with resonant regeneration and status of ALPS II at DESY

JURA: exploiting the power of modern dipole magnets

Summary
## ALP searches: different experimental approaches

<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 $g_{a\gamma\gamma}$</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Coupling · 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>Electron coupling</td>
<td>no</td>
<td>yes</td>
<td>no</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 allows for model independent searches and definite coupling determination.
New hints for ALPs from supernova remnants and pulsars:

- If the line-of-sight passes magnetic field regions photons might oscillate into ALPs.
  - The “missing photons” would introduce distinct spectral features.

- Such an effect seems to show up in a parameter region already excluded by CAST.
  - Suppression of ALP production in the sun?
  - More detailed spectral analyses seem to be required to confirm / disprove these observations. Ongoing with DESY-Zeuthen colleagues.

- LSW experiments will finally clarify the ALP-interpretation.
Single-pass LSW:


Need to be improved in sensitivity for $g_{\alpha\gamma\gamma}$ by about three orders of magnitude to probe astrophysical hints for ALPs.

- Stellar evolutions,
- TeV transparency of the universe,
- spectral features of SNR and pulsars.

Note: experimental sensitivity $\sim g_{\alpha\gamma\gamma}^4$. 
Realize the concept of resonant regeneration about 30 years after its first proposal.

> Mode-matched optical cavities before and behind the “wall”.

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

ALPS II at DESY:

> Collaboration of particle physics and aLIGO / GEO 600 groups (AEI Hanover, U. of Cardiff, U. of Gainesville (FL)).
> Optics R&D since 2012.
> Based on string of 10+10 straightened HERA dipole magnets.
> Construction of the experiment in the HERA tunnel started early 2018.
> Aim for start-up end of 2020.
Joint Undertaking on Research for Any-light particles

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to overcome the principle limitations of ALPS II:
- Limited field strength of the HERA dipoles (5.3 T),
- limited aperture (eff. 50 mm) limiting the length of optical resonators due to clipping.

A future option for searching axion-like particles through light-shining-through-a-wall experiments:

**JURA (Joint Undertaking on Research for Any light particles)**

Axel Lindner (DESY), Andrzej Siemko (CERN), Herman Ten Kate (CERN), Benno Willke (AEI Hanover)

29 July 2018
Joint Undertaking on Research for Any-light particles could be based on

- LHC dipoles,
- magnets under development for a HE-LHC or FCC (without the inner HTS section) and
- some (challenging) upgrades of the optics and detector systems.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensitivity</th>
<th>ALPS II</th>
<th>JURA</th>
<th>Rel. sensitivity JURA / ALPS II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet aperture</td>
<td></td>
<td>50 mm</td>
<td>100 mm</td>
<td></td>
</tr>
<tr>
<td>Magnetic field B</td>
<td>$g_{SW} \sim B^{-1}$</td>
<td>5.3 T</td>
<td>13 T</td>
<td>2.5</td>
</tr>
<tr>
<td>Magnetic length L</td>
<td>$g_{SW} \sim L^{-1}$</td>
<td>189 m</td>
<td>960 m</td>
<td>5.1</td>
</tr>
<tr>
<td>Effective laser power P</td>
<td>$g_{SW} \sim P^{-1/4}$</td>
<td>0.15 MW</td>
<td>2.5 MW</td>
<td>2.0</td>
</tr>
<tr>
<td>Power-built up Q (behind the wall)</td>
<td>$g_{SW} \sim Q^{-1/4}$</td>
<td>40,000</td>
<td>100,000</td>
<td>1.3</td>
</tr>
<tr>
<td>Detector noise DC</td>
<td>$g_{SW} \sim DC^{1/8}$</td>
<td>$10^{-4}$ 1/s</td>
<td>$10^{-6}$ 1/s</td>
<td>1.8</td>
</tr>
<tr>
<td>Total sens. increase</td>
<td></td>
<td></td>
<td></td>
<td>56</td>
</tr>
</tbody>
</table>

Table 1: Comparison of experimental parameters of ALPS II at DESY and the JURA proposal.
Joint Undertaking on Research for Any-light particles could reach sensitivities beyond IAXO for lightweight ALPs.

Figure 1: the experimental reach of JURA for ALP-photon couplings.
A stepwise approach of JURA

Proposed by the PBC technology subgroup (see presentation by A. Siemko):

- babyJURA: 1+1 LHC dipoles, optical system similar to ALPS II.
- JURA 1: 4+4 LHC dipoles, similar sensitivity as ALPS II.
- JURA 2: FCC dipoles (modified).

Due to the necessity of long strings of modern superconducting accelerator dipole magnets CERN appears to be a natural site for JURA.

The required optics expertise needs to be secured.

JURA activities could start in about 2023.
JURA drives model independent axion-like particle searches to its limits by combining “ultimate” dipoles, optics and detectors.

- In size and costs it would go significantly beyond any other experiment searching for lightweight Weakly Interacting Slim Particles (WISPs).
- At present the physics case is not settled, but this might quickly change with results from
  - ALPS II,
  - babyIAXO and later IAXO.
- To secure and bundle expertise (especially in optics) the start of “pre-JURA” activities should happen in parallel to ALPS II data taking (2022).

JURA could become the LHC for WISP searches!