Università
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Looking for the invisible

Light new physics and modified electrodynamics:
axions, scalars and dark photons
in *light-shining-through-wall* experiments

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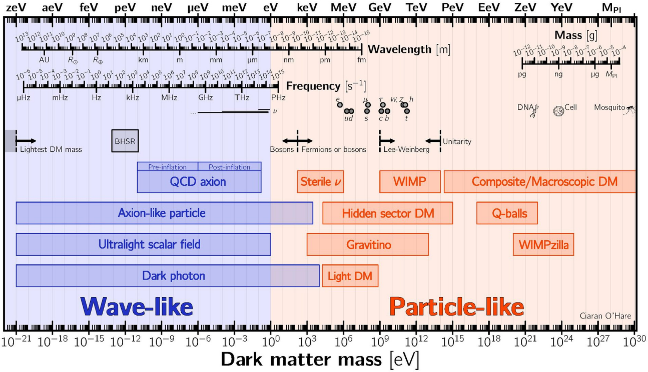
GraSPA Annecy

Nice to meet you!

- I'm Matteo Olivieri, a third-year undergraduate student at the University of Padua
- I'm passionate about the physics of fundamental interactions
- Long-term goal of studying (B)SM phenomenology

Why new light bosons?

$$\mathcal{L}_{QCD} \supset \theta \frac{g_s^2}{32\pi^2} G_{\mu\nu} \tilde{G}^{\mu\nu}$$



Modified Lagrangians

1. Pseudoscalar case (axions & ALPS):

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m_a^2\phi^2 - \frac{1}{4}g\phi F_{\mu\nu}\tilde{F}^{\mu\nu}$$

2. Scalar case:

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m_a^2\phi^2 + \frac{1}{4}g\phi F_{\mu\nu}F^{\mu\nu}$$

3. Vector case (dark photons):

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}X_{\mu\nu}X^{\mu\nu} + \frac{\chi}{2}X_{\mu\nu}F^{\mu\nu} + \frac{1}{2}m_{\gamma'}^2 X_\mu X^\mu$$

Wave equation

$$\left[\left(\omega^2+\partial_z^2\right)\mathbb{I}+\begin{pmatrix}2\omega^2(n_\perp-1) & 0 & 0\\ 0 & 2\omega^2(n_\parallel-1) & gB\omega\\ 0 & gB\omega & -m_\phi^2\end{pmatrix}\right]\begin{pmatrix}A_\perp\\ A_\parallel\\ \phi\end{pmatrix}=0$$

$$\Big\downarrow \; |n-1|\ll 1$$

$$i\partial_z\begin{pmatrix}A_\perp\\ A_\parallel\\ \phi\end{pmatrix}=\left[\omega\mathbb{I}+\begin{pmatrix}\Delta_\perp & 0 & 0\\ 0 & \Delta_\parallel & \Delta_g\\ 0 & \Delta_g & \Delta_\phi\end{pmatrix}\right]\begin{pmatrix}A_\perp\\ A_\parallel\\ \phi\end{pmatrix}$$

Oscillation probability

1. "Spatial evolution" operator $U(0,z) = e^{iHz}$
2. Oscillation amplitude:

$$\mathcal{A}_{\gamma\to\phi} = \langle\phi|\psi\rangle = (0,1)\cdot\psi(z) = (0,1)\cdot U(0,z)\begin{pmatrix}1\\0\end{pmatrix}$$

3. Oscillation probability:

$$\mathcal{P}_{\gamma\to\phi} = |\mathcal{A}_{\gamma\to\phi}|^2 = \left(\frac{gBL}{2}\right)^2 |\mathcal{F}(qL)|^2$$

LSW experiments

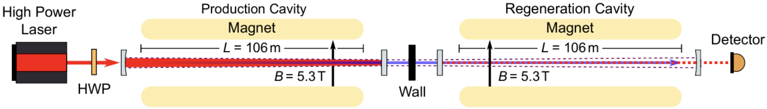


Figure: Functioning scheme of an LSW experiment

ALPS II @ DESY

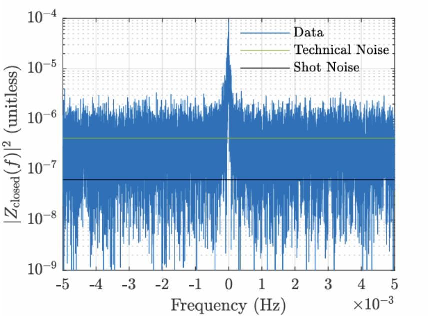


Figure: Detected signal in first ALPS II scientific run

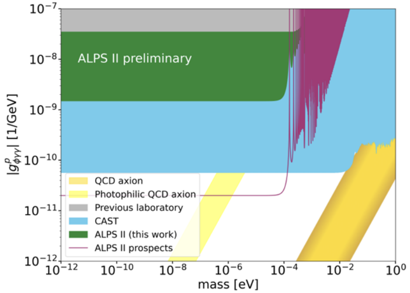


Figure: Axion parameter space and exclusion limits

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Back-up slides

Axion-Maxwell equations

- Bianchi identities:

$$\vec{\nabla} \times \vec{E} + \frac{\partial \vec{B}}{\partial t} = 0$$

$$\vec{\nabla} \cdot \vec{B} = 0$$

- Maxwell equations:

$$\vec{\nabla} \cdot \vec{E} = -g\vec{B} \cdot \vec{\nabla}\phi$$

$$\partial_t \vec{E} - \vec{\nabla} \times \vec{B} = g\left(\vec{E} \times \vec{\nabla}\phi - \vec{B}\partial_t\phi\right)$$

- Axion field equation of motion:

$$\left(\Box + m_a^2\right)\phi = g\vec{B} \cdot \vec{E}$$

Parameter	Value
Single dipole magnetic length	$L_{\mathrm{SD}} = (8826 \pm 2)\,\mathrm{mm}$
Dipole magnetic field strength	$B = (5.318 \pm 0.005)\,\mathrm{T}$
Number of dipoles	$2 \cdot N = 2 \cdot 12$
Gap between dipoles	$\Delta = (936 \pm 2)\,\mathrm{mm}$
Gap between strings	$(6290 \pm 5)\,\mathrm{mm}$

Figure: Experimental parameters of the ALPS II experiment

ALPS II data analysis

1. Open shutter runs:

$$P_{\text{open}} = T_M \eta^2 \beta_R P_i \tag{1}$$

2. Closed shutter runs:

$$P_\gamma = \mathcal{P}^2_{\gamma\to\phi} \eta^2 \beta_R P_i \tag{2}$$

3. Determination of $g_{\phi\gamma\gamma}$:

$$\mathcal{P}^2_{\gamma\to\phi} = T_M \frac{P_\gamma}{P_{\text{open}}} \tag{3}$$

Exclusion limits

Boson	95% CL limit
pseudoscalar	$g^p_{\phi\gamma\gamma} < 1.5 \cdot 10^{-9}\ \mathrm{GeV}^{-1}$
scalar	$g^s_{\phi\gamma\gamma} < 1.8 \cdot 10^{-9}\ \mathrm{GeV}^{-1}$
vector	$\epsilon < 2.1 \cdot 10^{-7}$
tensor, $\gamma_\perp$	$G'/G < 7.3 \cdot 10^{18}$
tensor, $\gamma_\parallel$	$G'/G < 6.6 \cdot 10^{18}$
tensor, combined	$G'/G < 5.4 \cdot 10^{18}$

Figure: Exclusion limits set by first ALPS II science run