Light-shining-through-thin-wall radio frequency cavities for probing dark photon and ALP

Dmitry Salnikov[1,2]
salnikov.dv16@physics.msu.ru
in collaboration with
Dmitry Kirpichnikov[1], Petr Satunin[1,2] and Leysan Valeeva[1,2]

[1]Institute for Nuclear Research of the Russian Academy of Science
[2]Lomonosov Moscow State University

arXiv: 2402.09899, 2405.04983

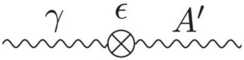
This research is supported by the RSF grant №21-72-10151.

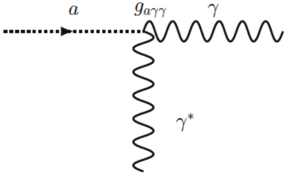
May 24, 2024

Introduction

- Dark photons (DP) and axion-like particles (ALPs) are hypothetical particles appearing in SM extensions.
- They are well motivated candidates for dark matter content.
- The interaction with photons is described as follows:

$$\mathcal{L}_{\mathrm{DP}} = \frac{\epsilon}{2} F'_{\mu\nu} F^{\mu\nu} \qquad \mathcal{L}_{\mathrm{ALP}} = -\frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu} \tilde{F}^{\mu\nu} \tag{1}$$





Current DP limitations

Caputo et al., 2105.04565

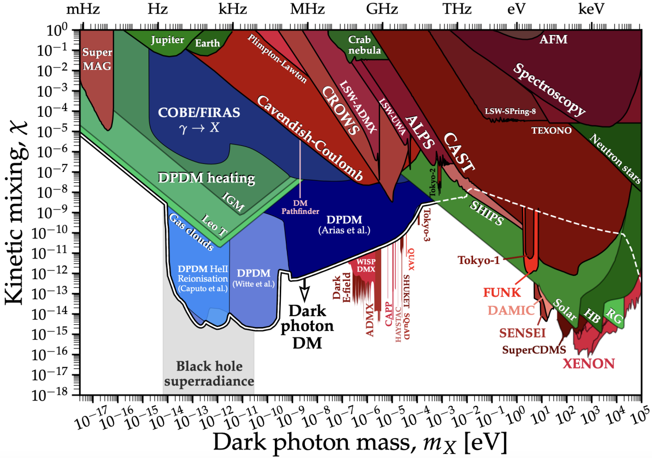


Figure 1 – The current limitations on parameters $(m_X\{m_{A'}\}, \chi\{\epsilon\})$ for DP

Current ALP limitations

Ringwald, 2404.09036

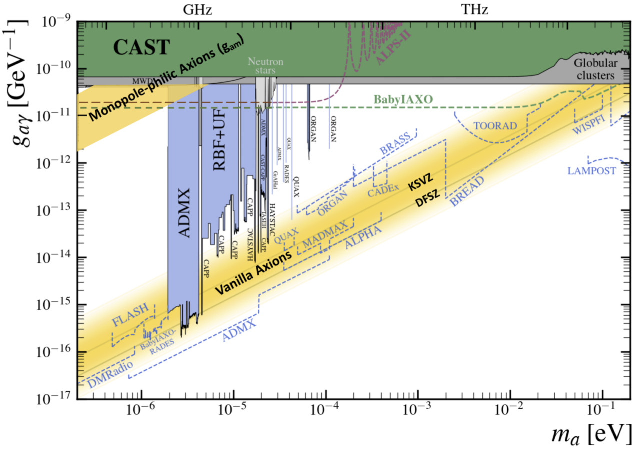


Figure 2 – The current limitations on parameters $(m_a, g_{a\gamma\gamma})$ for QCD axions and ALPs.

Light-Shining-through-Wall

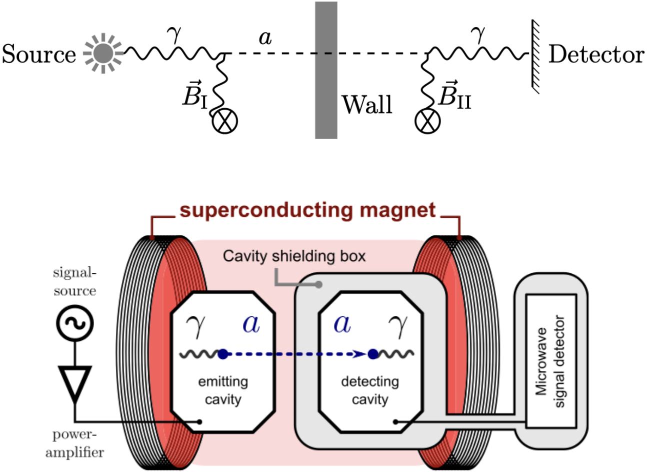


Figure 3 – The LSW setup scheme

LSW experimental setups

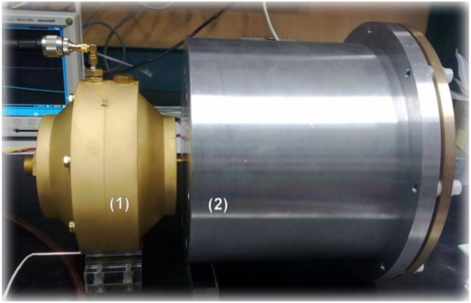


FIG. 7: Photo of emitting cavity (1) and shielding enclosure (2) containing the identical detecting cavity. For ALP search, both parts were placed in the bore of a solenoid magnet with the same arrangement as shown in the picture.

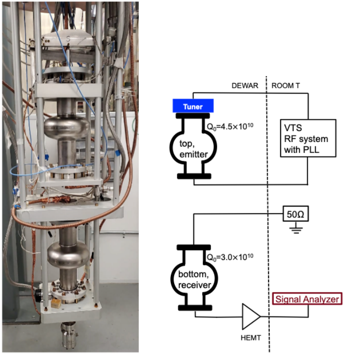
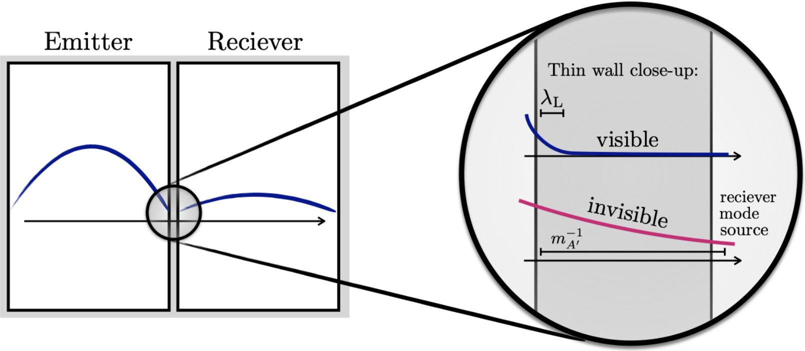


FIG. 1. Left: The experimental setup for the Dark SRF experiment consisting of two 1.3 GHz cavities. Right: A sketch of the Dark SRF electronic system.

Figure 4 – The LSW experimental setups photos. The left panel presents the CROWS experiment at CERN [Betz et al., 1310.8098]. The right panel presents the current Fermilab experimental setup [Romanenko et al., 2301.11512].

Thin wall

Berlin et al., 2303.00014



$$d \gtrsim 10\,\mu\text{m}, \quad m_{A'} \gg \omega \sim 10^{-7}\,\text{eV} \sim \text{GHz} \tag{2}$$

LSW setup schemes

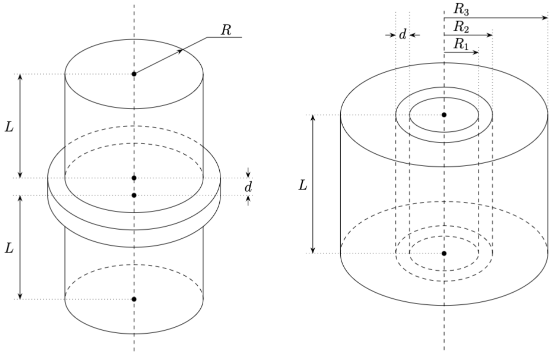


Figure 5 – The experimental model schemes for two receiver location: separated (the left panel) and nested (the right panel).

	Separated	Nested
R	10 cm	10 cm
L	5 cm	10 cm
d	10 μm, 1 mm, 1 cm	

Experiment sensitivity

- The signal power

$$P_{\text{signal}} = \frac{\omega_s}{Q_{\text{rec}}} \int\limits_{V_{\text{rec}}} d^3x \, \langle |\vec{E}^2(\vec{x},t)| \rangle_t = \frac{\omega_s}{Q_{\text{rec}}} \cdot \frac{1}{2} |G|^2 V_{\text{rec}} \;, \qquad (3)$$

where G is the amplitude of the signal EM-mode.

- The radiometric equation

$$\text{SNR} = \frac{P_{\text{signal}}}{P_{\text{noise}}} \cdot \sqrt{t \Delta\nu} \;, \qquad (4)$$

where $P_{\text{noise}} = T\Delta\nu$ – the thermal noise power ($\omega_s \ll T$).

Amplitude and Geometric Form Factor

- ALP

$$G = \mathcal{G}\, g_{a\gamma\gamma}^2 E_0^{\text{em}} B_{\text{ext}}^2 Q_{\text{rec}} V_{\text{em}} \omega, \tag{5}$$

$$\mathcal{G} = \int_{V_{\text{rec}}} \frac{d^3x}{V_{\text{rec}}} \int_{V_{\text{em}}} \frac{d^3x'}{V_{\text{em}}} \mathcal{E}_B^{*\text{rec}}(\vec{x}) \mathcal{E}_B^{\text{em}}(\vec{x}') \frac{e^{ik_a|\vec{x}-\vec{x}'-\vec{l}|}}{4\pi\omega|\vec{x}-\vec{x}'-\vec{l}|}. \tag{6}$$

$$k_a = \sqrt{\omega^2 - m_a^2} \tag{7}$$

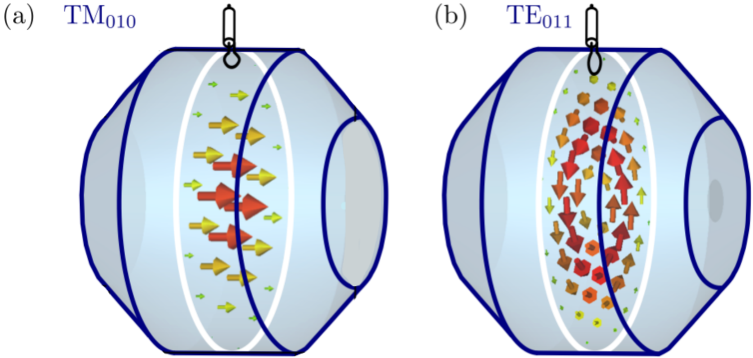
- DP

$$G = \mathcal{G}\, \epsilon^2 m_{A'}^2 E_0^{\text{em}} Q_{\text{rec}} V_{\text{em}} \omega, \tag{8}$$

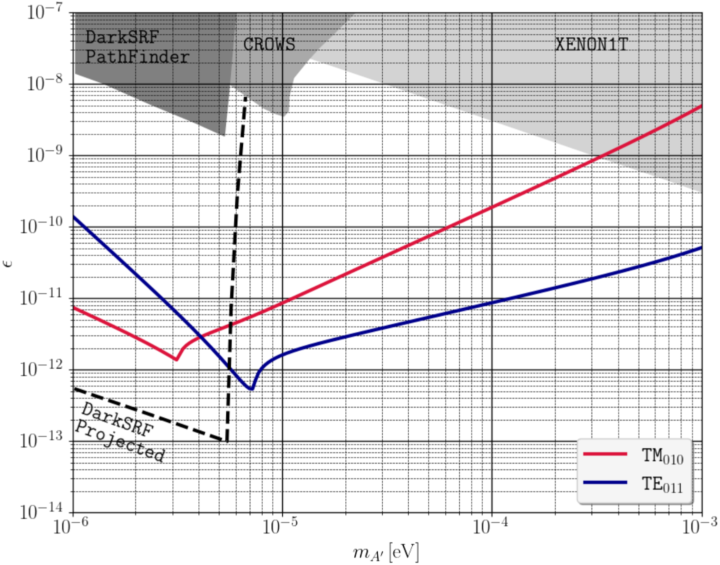
$$\mathcal{G} = \frac{1}{\omega^2} \int_{V_{\text{rec}}} \frac{d^3x}{V_{\text{rec}}} \int_{V_{\text{em}}} \frac{d^3x'}{V_{\text{em}}} \mathcal{E}_{\text{rec}}^{i*}(\vec{x}) \mathcal{E}_{\text{em}}^{j}(\vec{x}')(m_{A'}^2 - \partial_i\partial_j) \frac{e^{ik_{A'}|\vec{x}-\vec{x}'-\vec{l}|}}{4\pi\omega|\vec{x}-\vec{x}'-\vec{l}|}. \tag{9}$$

$$k_{A'} = \sqrt{\omega^2 - m_{A'}^2} \tag{10}$$

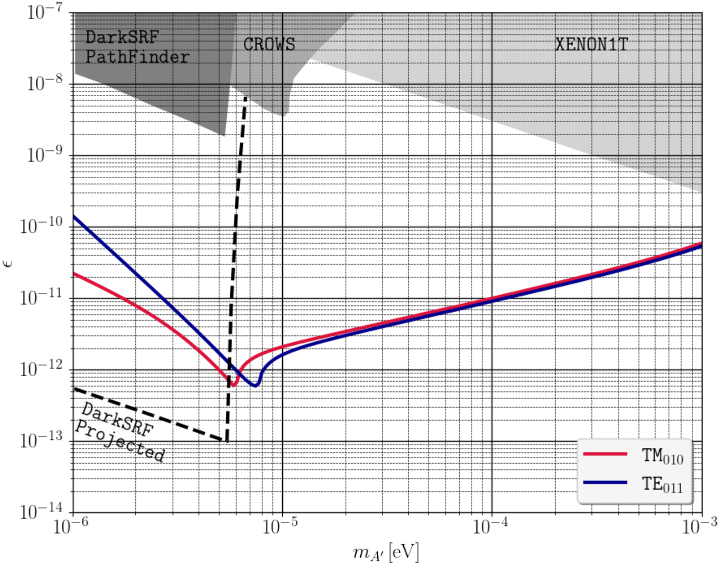
TM_{010} and TE_{011} modes



Separated receiver



Nested receiver



Asymptotic behaviour of ϵ at high masses

- Separated receiver, TM_{010}

$$\mathcal{G} \propto \frac{(m_{A'}d)^2}{m_{A'}^4}\left[K_2(m_{A'}d) - K_0(m_{A'}d)\right] \propto \frac{\exp(-m_{A'}d)}{m_{A'}^{\frac{7}{2}\div 4}} \tag{11}$$

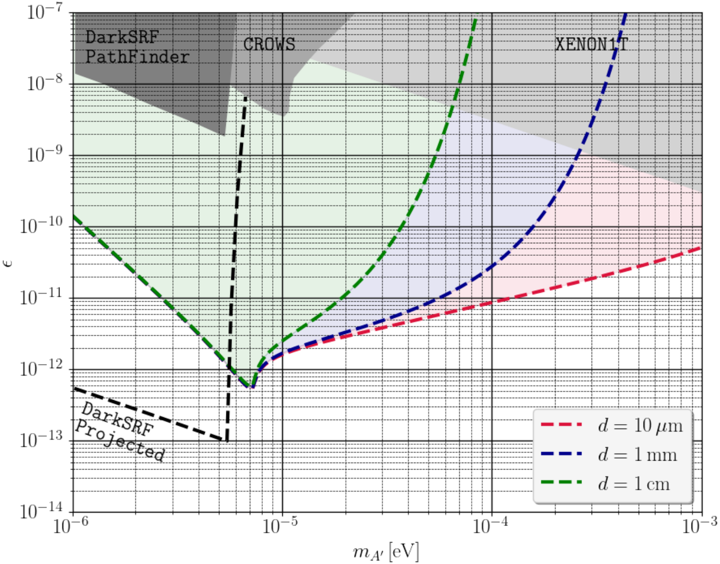
$$\epsilon \propto m_{A'}^{\frac{3}{4}\div 1} \times \exp\left(\frac{m_{A'}d}{2}\right) \tag{12}$$

- Other cases

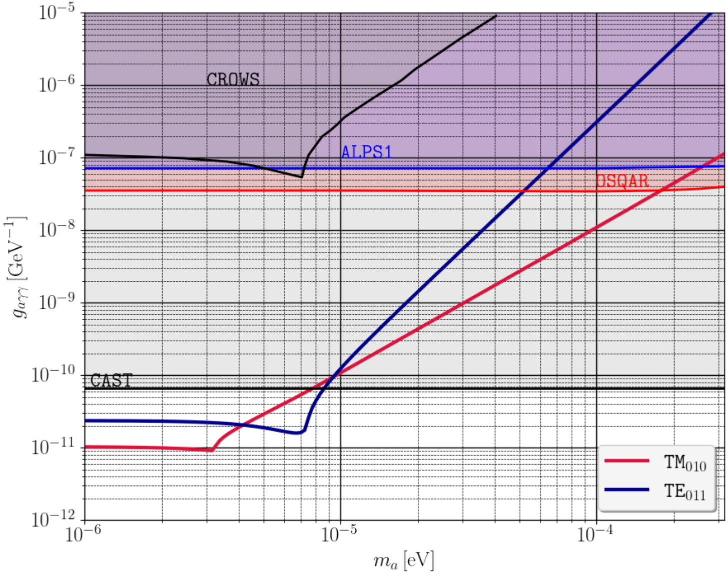
$$\mathcal{G} \propto \frac{\exp(-m_{A'}d)}{m_{A'}^3} \tag{13}$$

$$\epsilon \propto m_{A'}^{\frac{1}{2}} \times \exp\left(\frac{m_{A'}d}{2}\right) \tag{14}$$

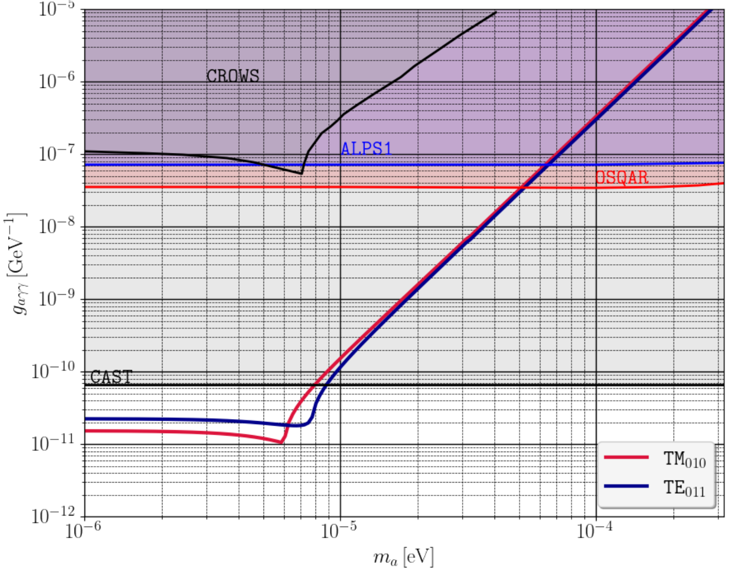
Dependence on d



Separated receiver



Nested receiver



Asymptotic behaviour of $g_{a\gamma\gamma}$ at high masses

- Separated receiver, TM_{010}

$$\mathcal{G} \propto \frac{\exp(-m_a d)}{m_a^3} \tag{15}$$

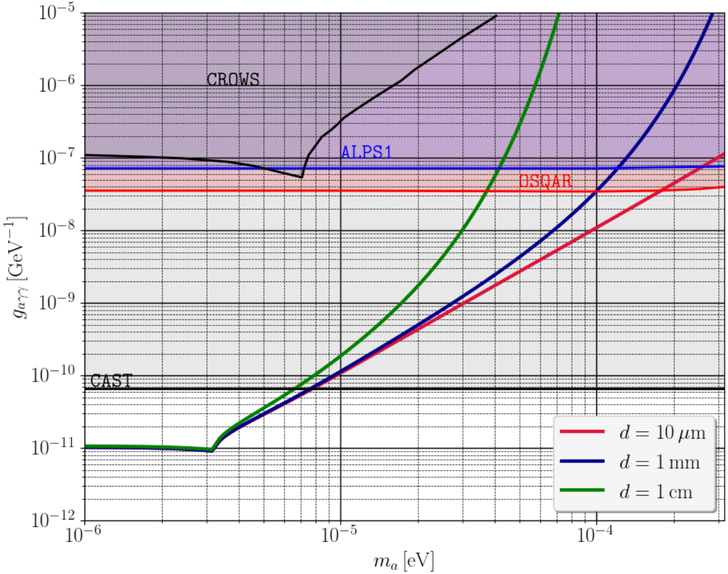
$$g_{a\gamma\gamma} \propto m_a^{\frac{3}{2}} \times \exp\left(\frac{m_a d}{2}\right) \tag{16}$$

- Other cases

$$\mathcal{G} \propto \frac{\exp(-m_a d)}{m_a^5} \tag{17}$$

$$g_{a\gamma\gamma} \propto m_a^{\frac{5}{2}} \times \exp\left(\frac{m_a d}{2}\right) \tag{18}$$

Dependence on d



Results

- The LSW cavity setups with thin wall for DP and ALP search were considered
- It has been shown that using a thin-wall installation, it is possible to significantly increase the coverage area
- Asymptotical approximations of sensitivity at high masses were analytically calculated

Thank you!