16th Patras Workshop on
Axions, WIMPs and WISPs

Examining axion-like particles with superconducting radio-frequency cavity

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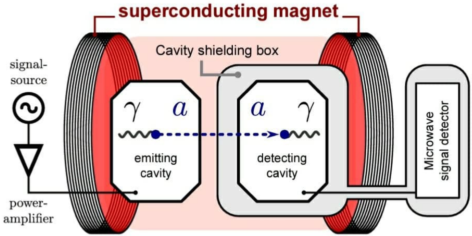
LSW-type experiments

Traditional LSW experiments with microwaves with RF cavities

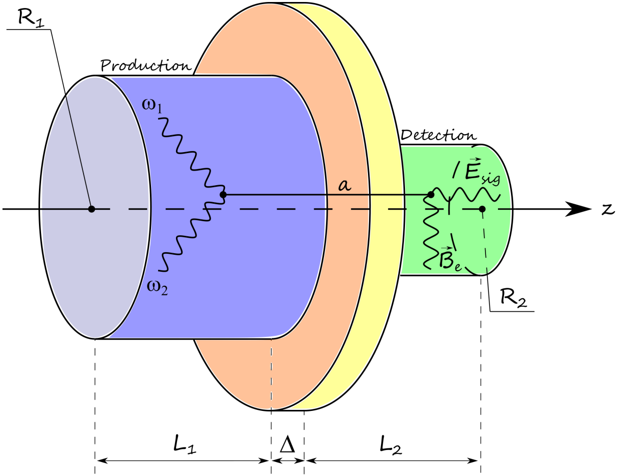


- ALP Production: EM cavity mode + magnetic field → ALP
- ALP Detection: ALP + magnetic field → signal mode

SRF cavities — larger quality factor and amplitudes for EM modes
but external magnetic field destroys superconducting state

- In SRF cavities additional EM mode instead of magnetic field

The scheme of the proposed setup



Condition on the surface magnetic field for a pump mode: $|B| < 0.1$ T.

Axion electrodynamics

- The Lagrangian

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}\partial_\mu a\,\partial^\mu a - \frac{1}{2}m_a^2 a^2 + \frac{g_{a\gamma\gamma}}{4}\,a\,F_{\mu\nu}\tilde{F}^{\mu\nu}\ , \qquad (1)$$

- ALP production: two cavity modes $\mathbf{TM_{npq}}(\omega_1) + \mathbf{TE_{mlk}}(\omega_2)$

$$(\partial_\mu\partial^\mu + m_a^2)\,a(\vec{x},t) = \frac{g_{a\gamma\gamma}}{4}\mathbf{F}_{\mu\nu}\tilde{\mathbf{F}}^{\mu\nu}, \qquad (2)$$

$$a(\vec{x},t) = a_+(\vec{x},t) + a_-(\vec{x},t), \qquad \omega_\pm = \omega_1 \pm \omega_2.$$

$$a_\pm(\vec{x},t) = -\frac{g_{a\gamma\gamma}}{4\pi}\mathrm{e}^{-i\omega_\pm t}\int\limits_{V_{cav}} \mathrm{d}^3x'\,\frac{(\vec{E}\cdot\vec{B})_\pm(\vec{x}')}{|\vec{x}-\vec{x}'|}\cdot\mathrm{e}^{ik_\pm|\vec{x}-\vec{x}'|}. \qquad (3)$$

- ALP detection:

$$\partial_\mu F^{\mu\nu} = g_{a\gamma\gamma}\,\tilde{F}^{\mu\nu}\partial_\mu a. \qquad (4)$$

Comparison of $\langle \rho_+^E \rangle$ and $\langle \rho_-^E \rangle$

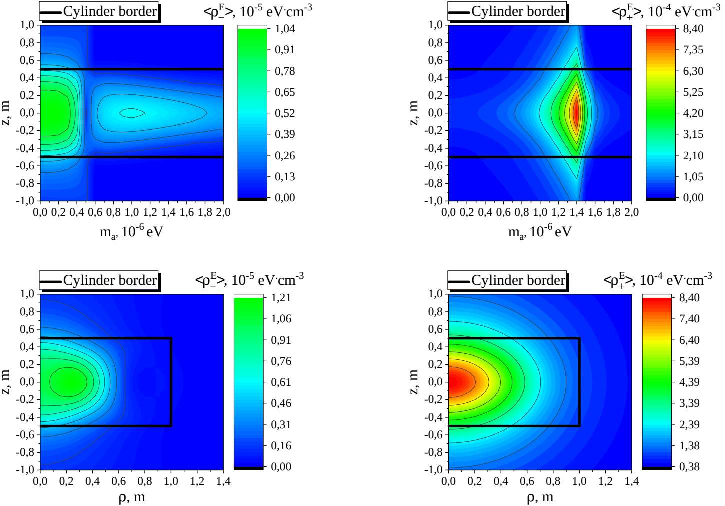


Figure 2 - The time-averaged energy density of ALPs for $TM_{010} + TE_{011}$ pump modes

Comparison of various combinations of pump modes

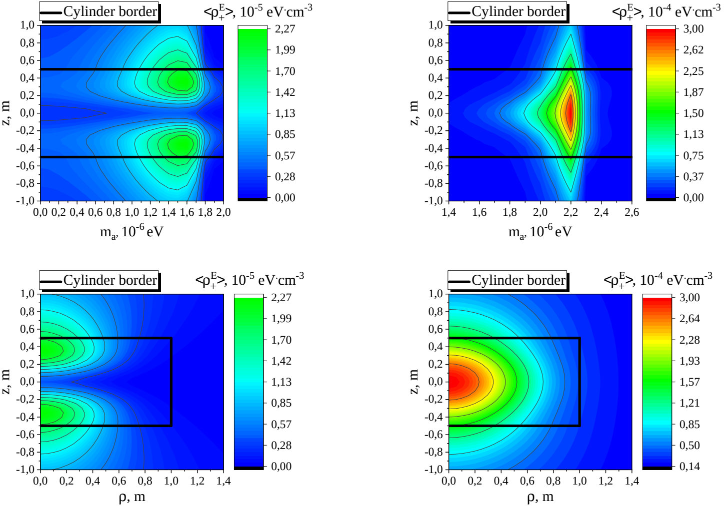


Figure 3 - The time-averaged energy density of ALPs for $TM_{011} + TE_{011}$ and $TM_{011} + TE_{012}$ pump modes

Comparison of various geometry of cavity

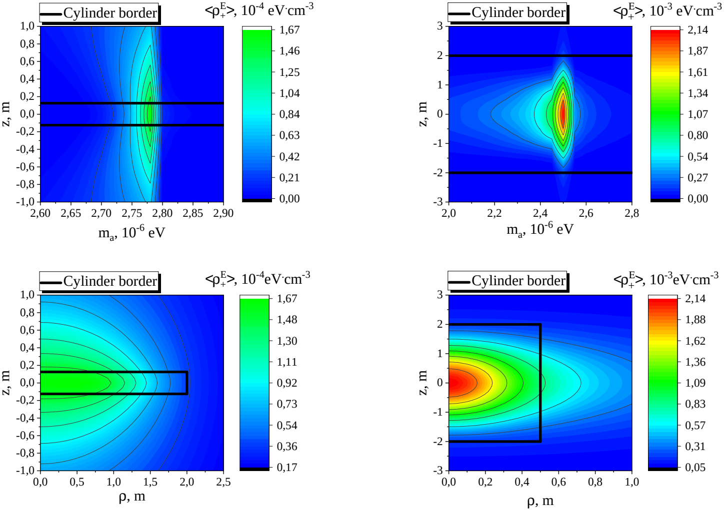


Figure 4 - The time-averaged energy density of ALPs for $TM_{010} + TE_{011}$ pump modes for various cavity geometry

Radiation pattern

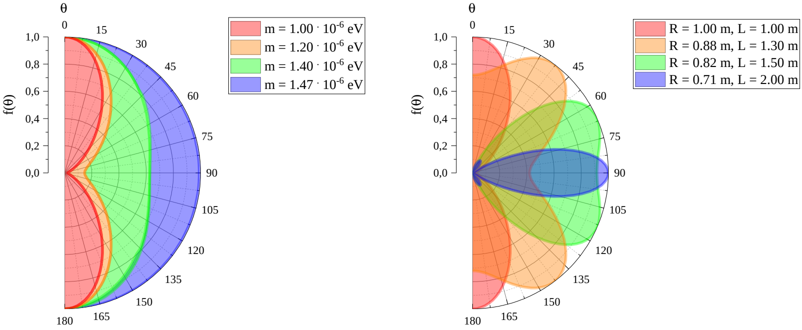


Figure 5 - Radiation pattern for $TM_{010} + TE_{011}$ pump modes for various masses of ALPs and cylindrical cavity geometry

Experimental model sensitivity

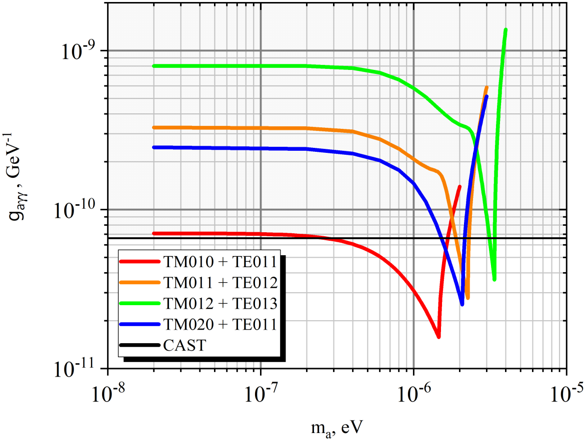


Figure 6 - Dependence of the coupling constant $g_{a\gamma\gamma}$ on the mass of ALPs m_a for various pump modes of the *production* cavity for the TM_{010} mode of the *detecting* cavity

References

- More detailed results are posted in the article:

  D. Salnikov, P. Satunin, D. Kirpichnikov, M. Fitkevich, «Examining axion-like particles with superconducting radio-frequency cavity». J. High Energ. Phys. 2021, **143** (2021). doi:10.1007/JHEP03(2021)143 [arXiv:2011.12871 [hep-ph]];

- The program code is posted on the website: https://github.com/dmitry-salnikov-msu/Axion.

Thank you for attention!