DMRadio-m^3: an overview

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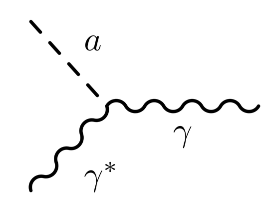
Background and Motivation

The Dark Matter Radio (DMRadio) experiment searches for dark matter axions using the conversion of axions into photons in the presence of a magnetic field.

$$\mathcal{L}_{ax} \sim -\frac{1}{4} g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu} = g_{a\gamma\gamma} a \mathbf{E} \cdot \mathbf{B}$$



This interaction gives rise to an effective axion current in Maxwell's equations:

$$\mathbf{J} \sim g_{a\gamma\gamma} \sqrt{2\rho_{\mathrm{DM}}} \cos(m_a t) \mathbf{B}$$

Search for axions by observing electromagnetic response to effective axion current in a resonant structure.

Science goals of DMRadio-m^3

KSVZ Dark Matter Axions

10 – 200 MHz (41 neV – 0.83 μeV)

DFSZ Dark Matter Axions

30 – 200 MHz (0.12 μeV– 0.83 μeV)

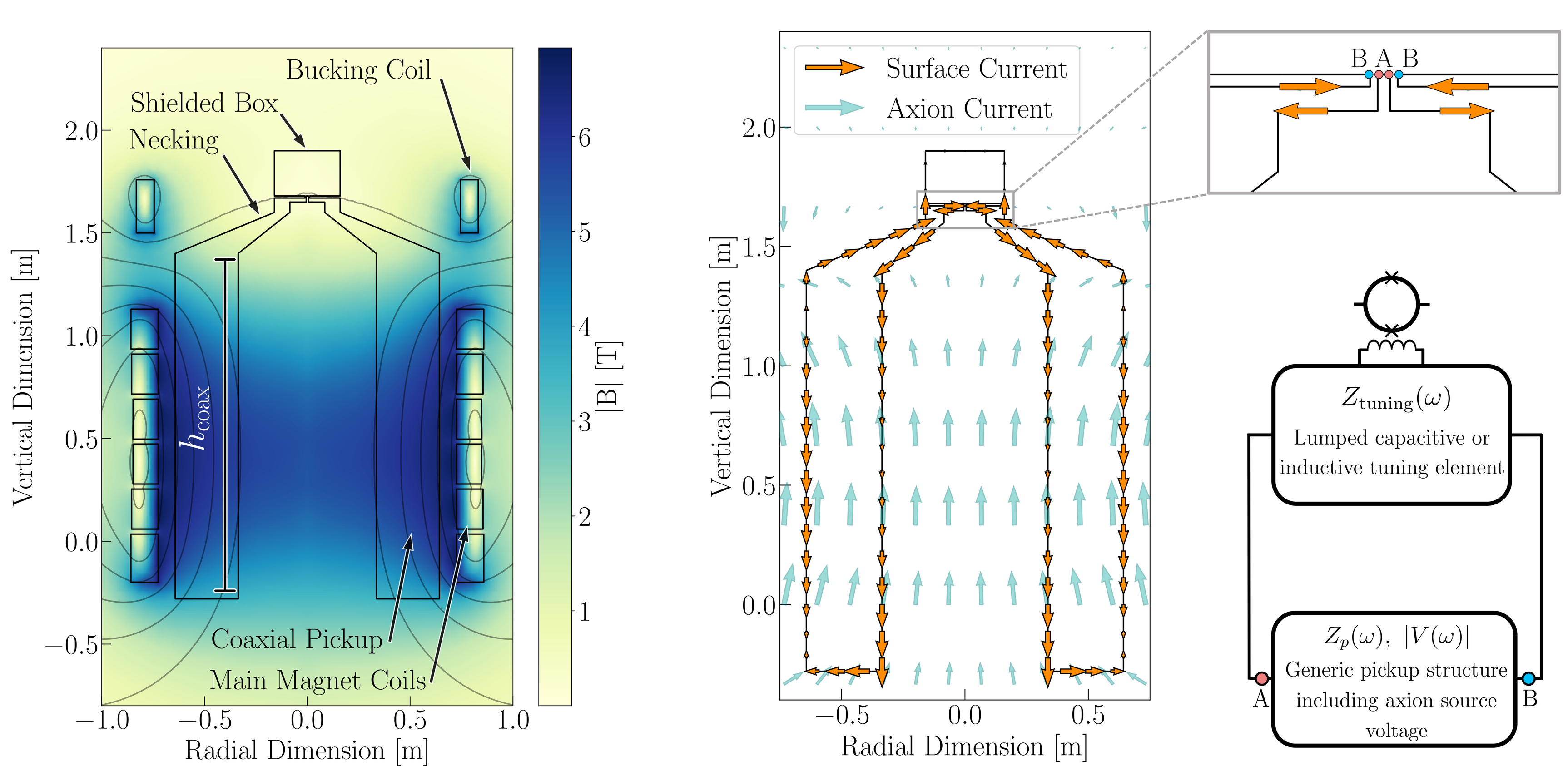
Operating principle of DMRadio-m^3

Effective axion current induces a current on the inner surface of coaxial pickup in a solenoidal $B_0 \approx 5$ T field.

Shielded Box contains

a. tuning elements, which shift a TEM-like resonance frequency of coaxial pickup

b. dc Superconducting Quantum Interference Device (SQUID) readout electronics



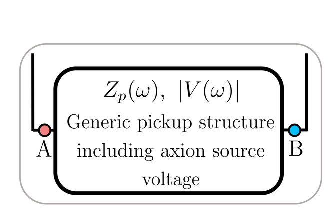
Scan Rate

$$\frac{d\nu}{dt} = \frac{\pi (6.4 \times 10^5) |V(m_a, B, g_{a\gamma\gamma})|^4 Q(\nu_r) \bar{\mathcal{G}}[\nu_r, T, \eta(\nu_r)]}{16\, \mathrm{SNR}^2 m_a^4 L_{\mathrm{eff}}(\nu_r)^2}$$

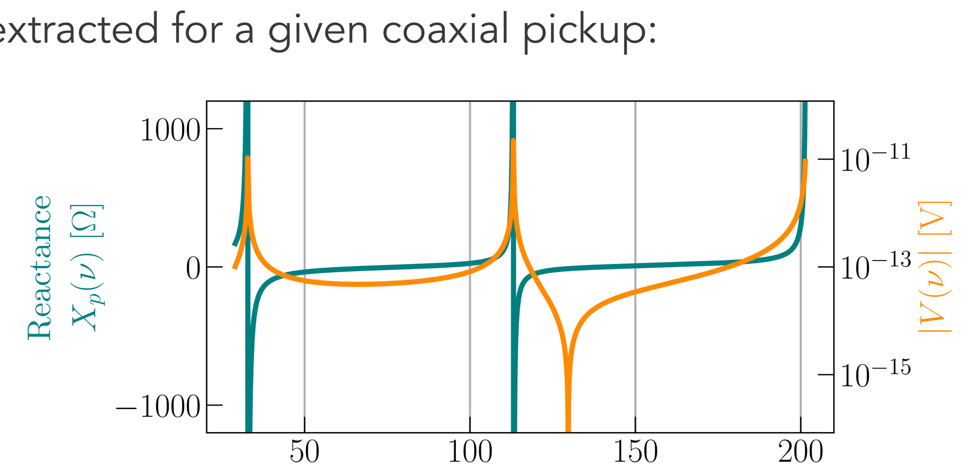
DM halo physics · Axion induced voltage · Quality Factor · Noise physics · Effective inductance

Extracting the sensitivity & tuning

dc SQUIDs and tuning elements connected across slit defined by points A and B in figure above.



Impedance ($Z_p(\nu) = R_p(\nu) + iX_p(\nu)$) and voltage across slit are numerically extracted for a given coaxial pickup:



Reactance qualitatively resembles that of a shorted coaxial line. Zeroes and asymptotes of the reactance are TEM-like resonances. These coaxial pickups also support TE modes which must be avoided.

To achieve resonance at any frequency, reactance must be tuned to zero:

$$X_{\mathrm{tot}}(\nu_0) = X_{\mathrm{tuning}}(\nu_0) + X_p(\nu_0) = 0$$

Use simulated reactance to model pickup as effective series-RLC circuit at each frequency.

- L_{eff}, quality factor, and extracted voltage enter the scan rate (Ref [1]).

Depending on sign of reactance, tuning element will be either inductive or capacitive

DMRadio-m^3 projected limits

DMRadio-m^3 uses a set of six coaxes with different heights (h_{coax}) :

a. maintains a high scan rate throughout the targeted frequency range.

b. avoids TE modes

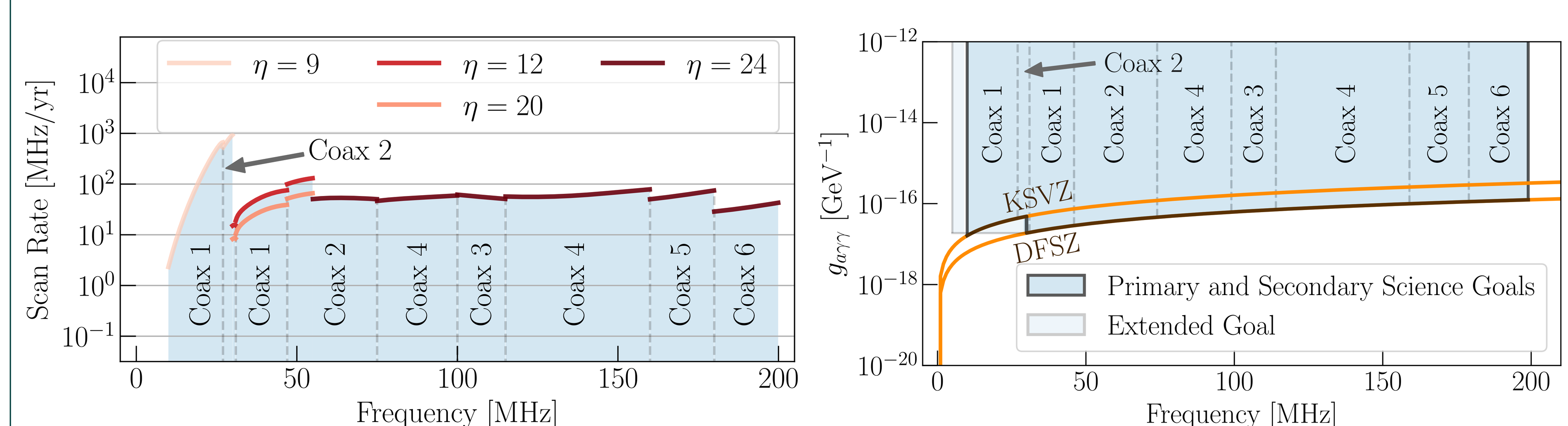
Different SQUID amplifiers are used, characterized by a noise parameter $\eta(\nu_r)$:

$$\eta(\nu_r) \equiv \frac{k_B T_N^{\min}(\nu_r)}{h\nu_r/2} \geq 1$$

For DMRadio-m^3 T = 20 mK

Quality factor expected: 100,000-300,000

Scan Time and Coaxes

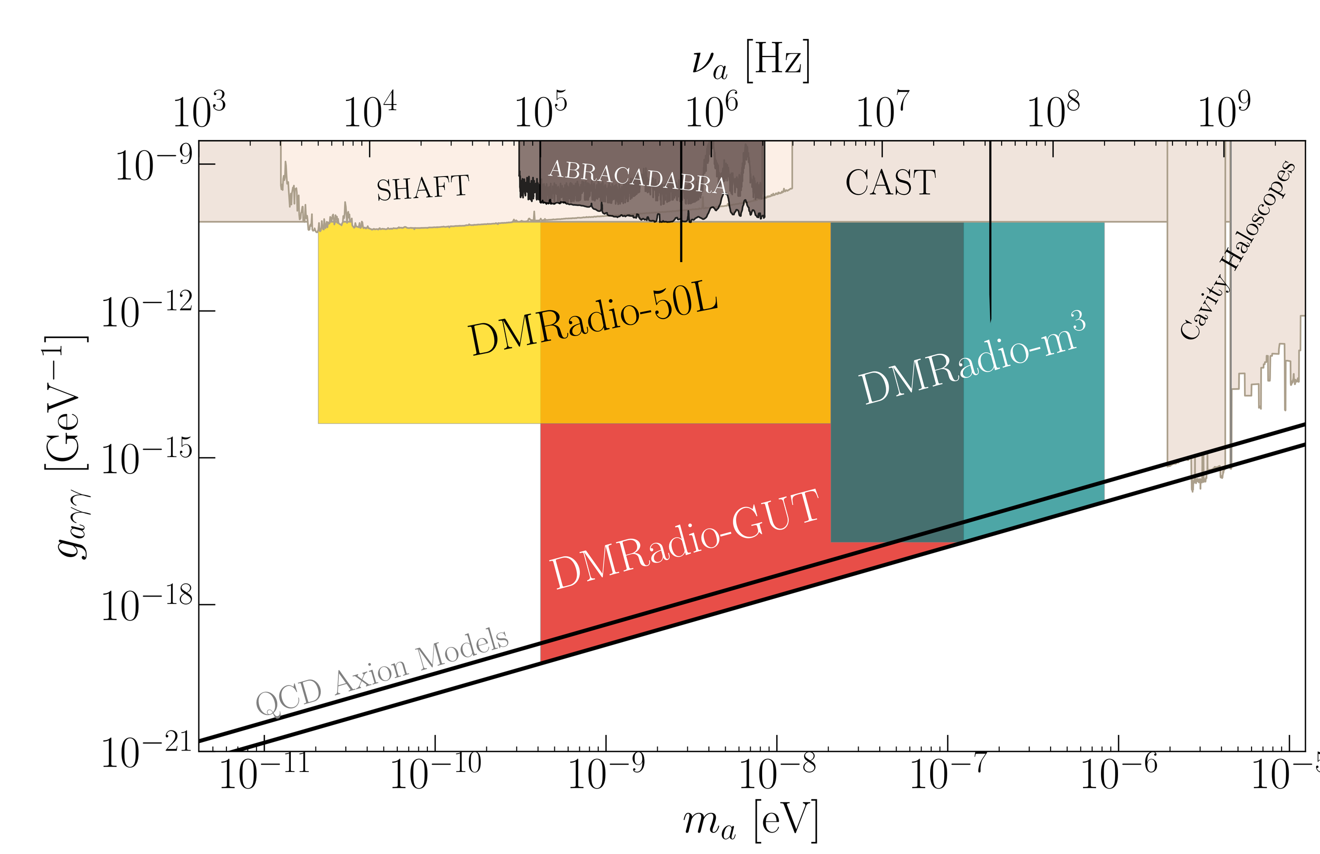


	Sensitivity & Range	3σ Live Scan Time
Primary Science Goal	DFSZ; 30–200 MHz	3.7 yr
Secondary Science Goal	KSVZ; 10–30 MHz	0.9 yr
Extended Goal	1.87×10^{-17} GeV^{-1}; 5–30 MHz	2.6 yr

Preliminary designs of coaxial pickup [2] and SQUIDs [3] have been completed.

Part of DOE Dark Matter New Initiatives program | To be built at SLAC National Lab

DMRadio Collaboration



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References

[1] S. Chaudhuri et al., "Optimal Impedance Matching and Quantum Limits of Electromagnetic Axion and Hidden-Photon Dark Matter Searches", arXiv:1803.01627 [hep-ph]

[2] A. AlShirawi *et al.*, "Electromagnetic modeling and science reach of DMRadio-m^3", arXiv:2302.14084.

[3] L. Brouwer *et al.*, "DMRadio-m^3: A Search for the QCD Axion Below 1 μeV", Phys.Rev.D **106** (2022) 10, 103008, arXiv:2204.13781.

[4] L. Brouwer *et al.*, "Proposal for a definitive search for GUT-scale QCD axions", Phys.Rev.D **106** (2022) 11, 112003, arXiv:2203.11246.

[5] C. Bartram, *et al.*, "Noise limits for dc SQUID readout of high-Q resonators below 200 MHz", (2023) to appear.