Calibrating the DMRadio Axion Dark Matter Detectors

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DMRadio Collaboration

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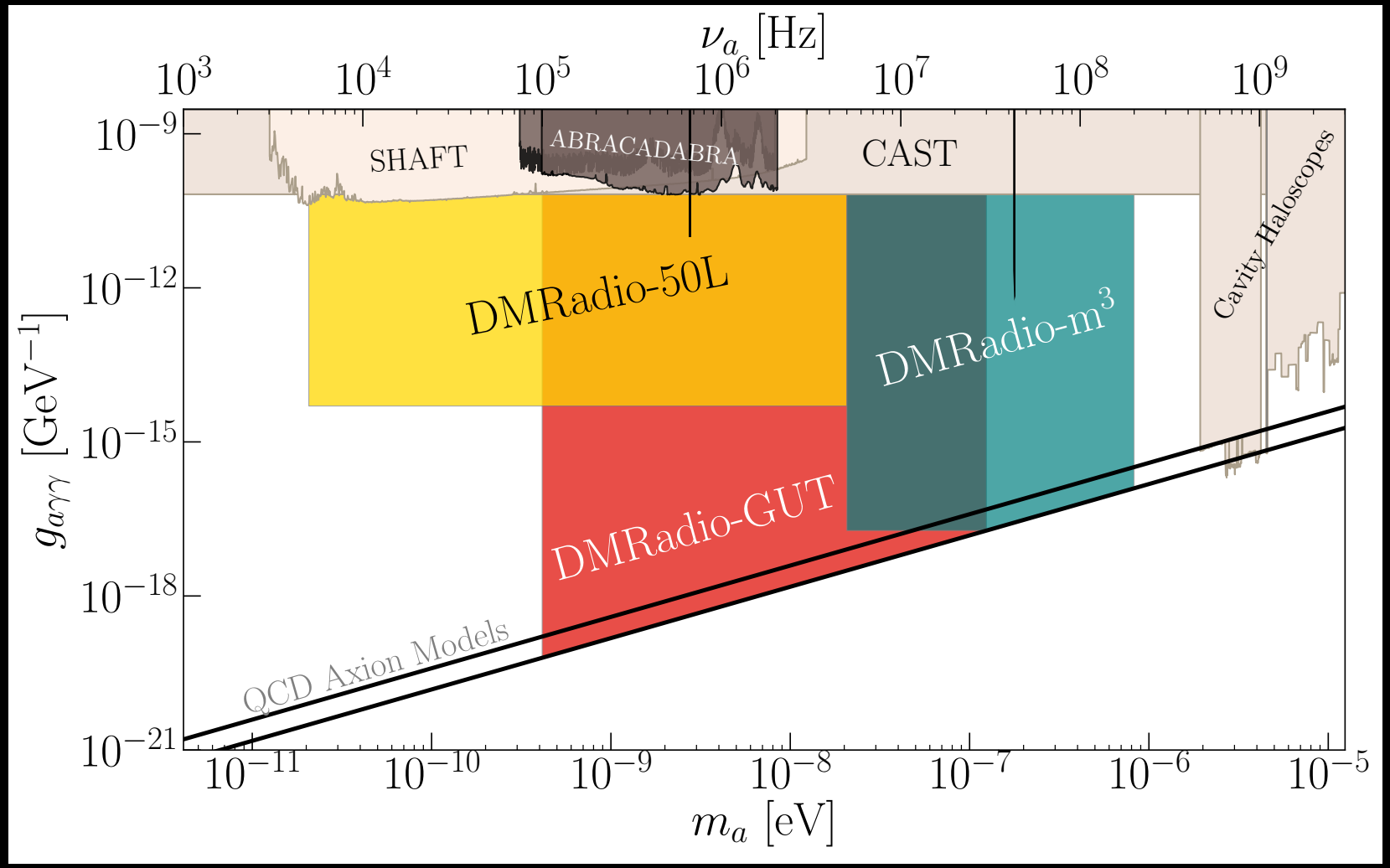
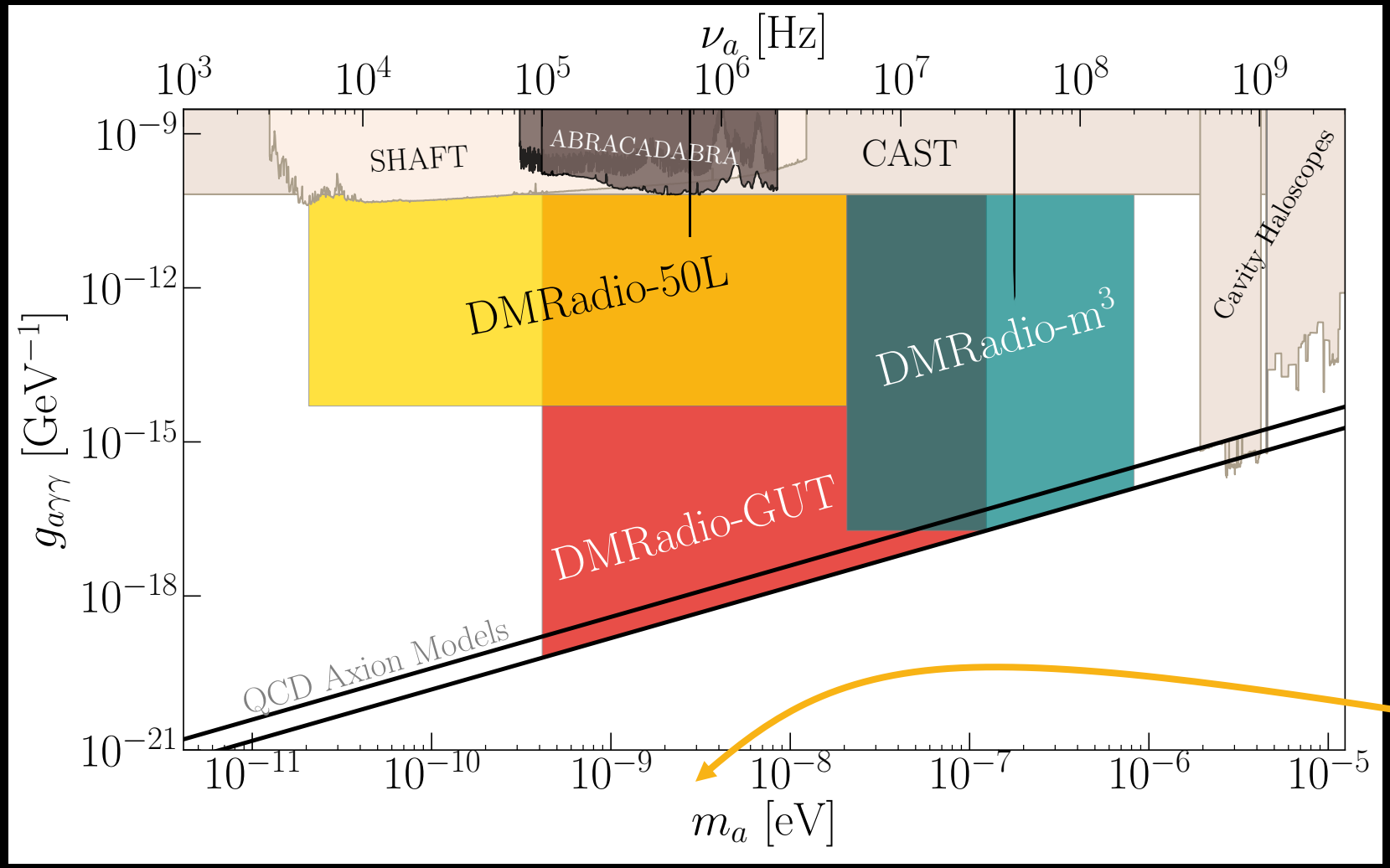
DMRadio


ν_a [Hz]
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^{-9}
10^{-12}
10^{-15}
10^{-18}
10^{-21}
$g_{a\gamma\gamma}$ [GeV^{-1}]
SHAFT
ABRACADABRA
CAST
Cavity Haloscopes
DMRadio-50L
DMRadio-m^3
DMRadio-GUT
QCD Axion Models
10^{-11}
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
m_a [eV]

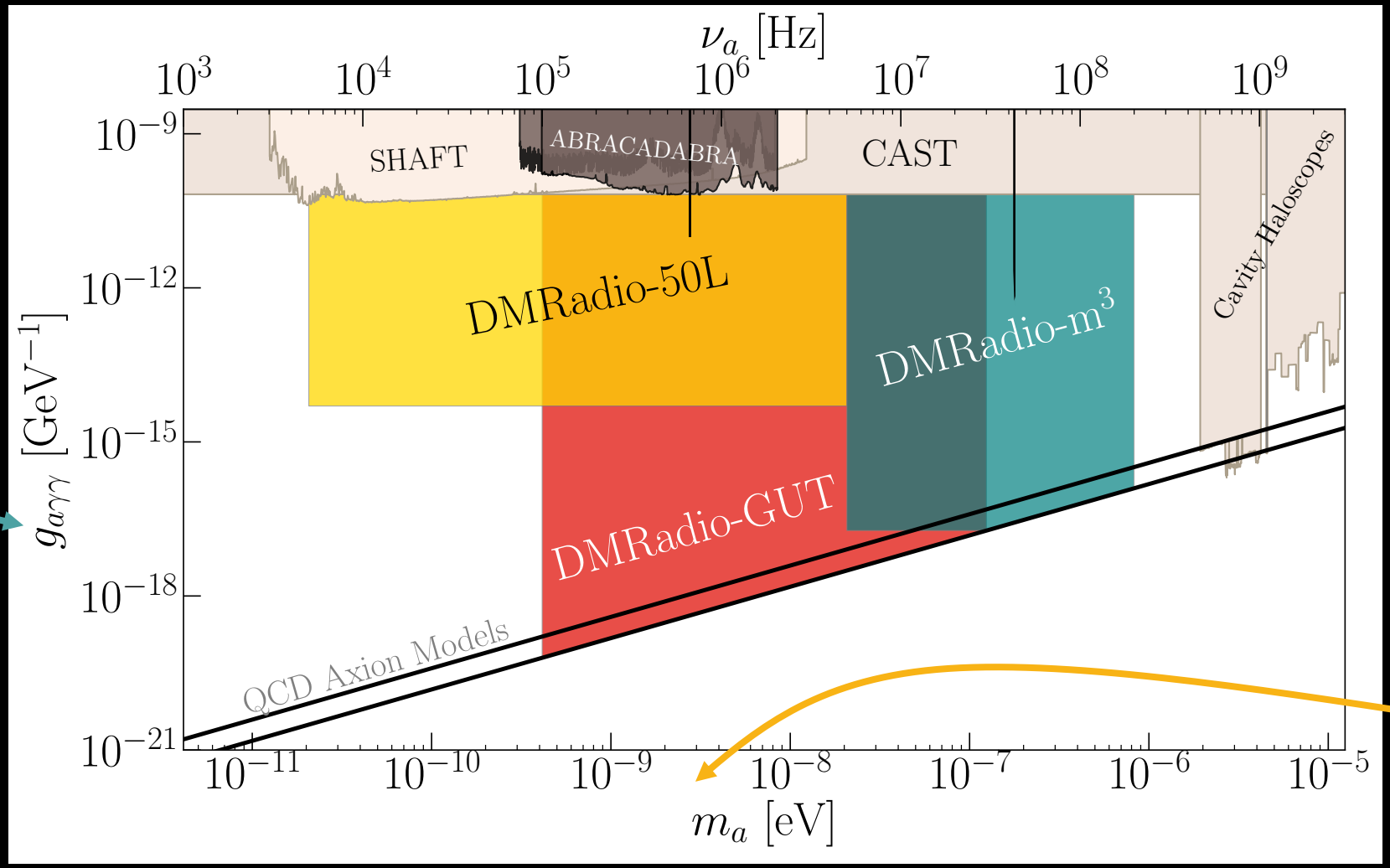
DMRadio



m_a given by frequency of oscillating field

DMRadio

Axion to photon coupling, $g_{a\gamma\gamma}$, given by axion induced flux power

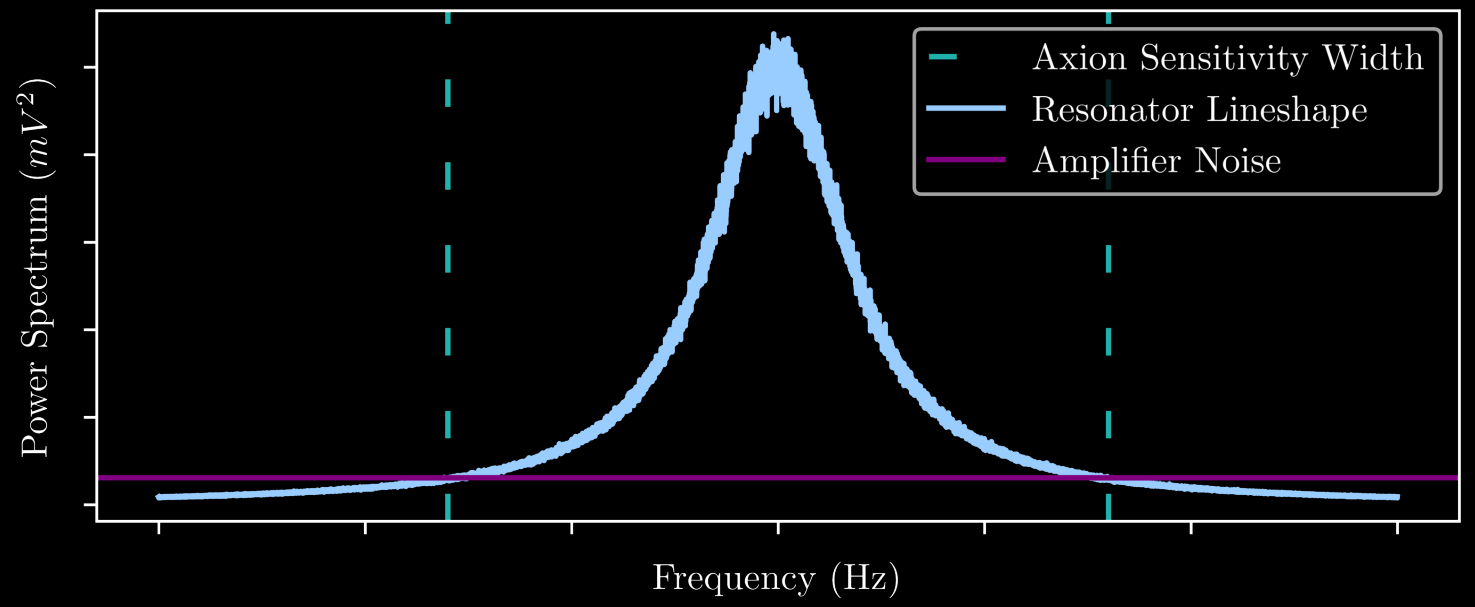


m_a given by frequency of oscillating field

Calibration Goals

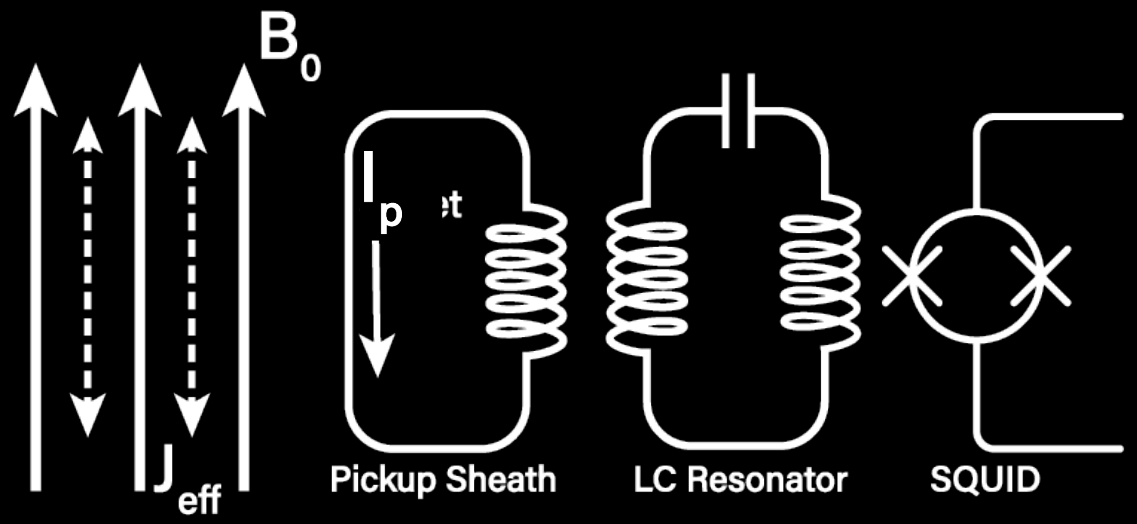
1. Characterize end-to-end gain of the system for all tuning steps
   DAQ readout voltage to $g_{a\gamma\gamma}$ conversion

2. Calibrate resonant frequency at each tuning step
   ω_0 and Q of resonant components



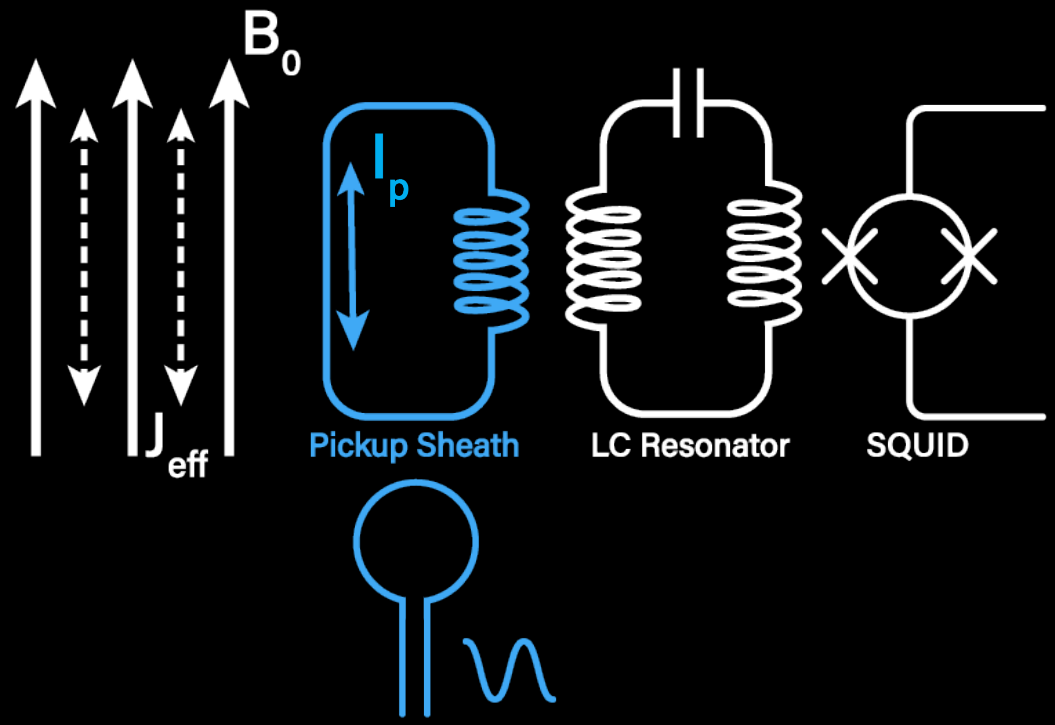
Calibration Methods

1. Excite pickup structure to perform end-to-end calibration
   - Axion mimetic injection
2. Measure individual components to get ω_0, amplification, and Q factor
   - Sideband injection
   - Frequency sweep
   - Ringdown measurement



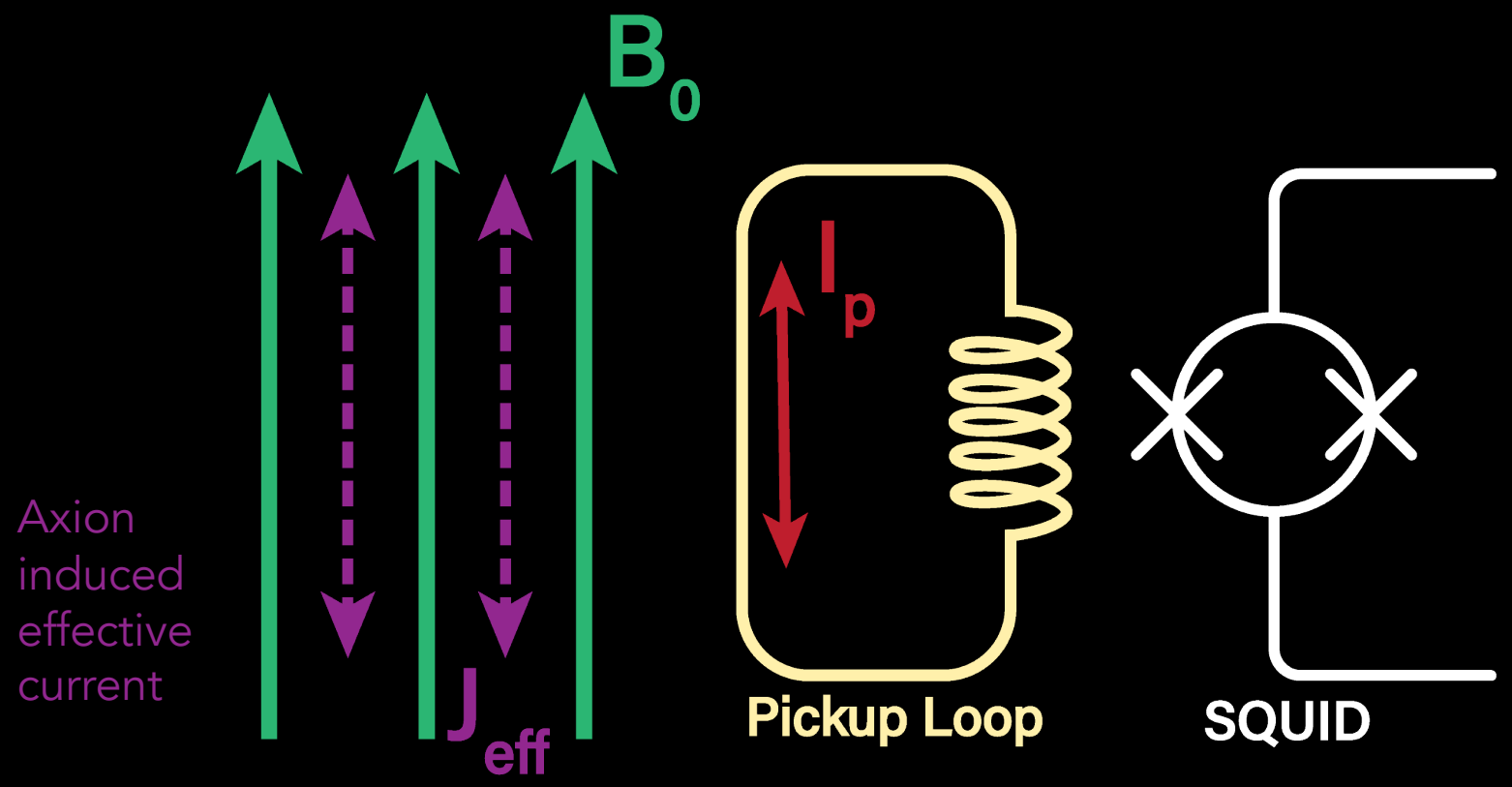
Axion Mimetic Injection

- Excite axion-like flux in pickup structure
- Ratio of injected voltage to readout voltage gives end-to-end gain
- Varies based on geometry
- Demonstrated with ABRACADABRA



ABRACADABRA

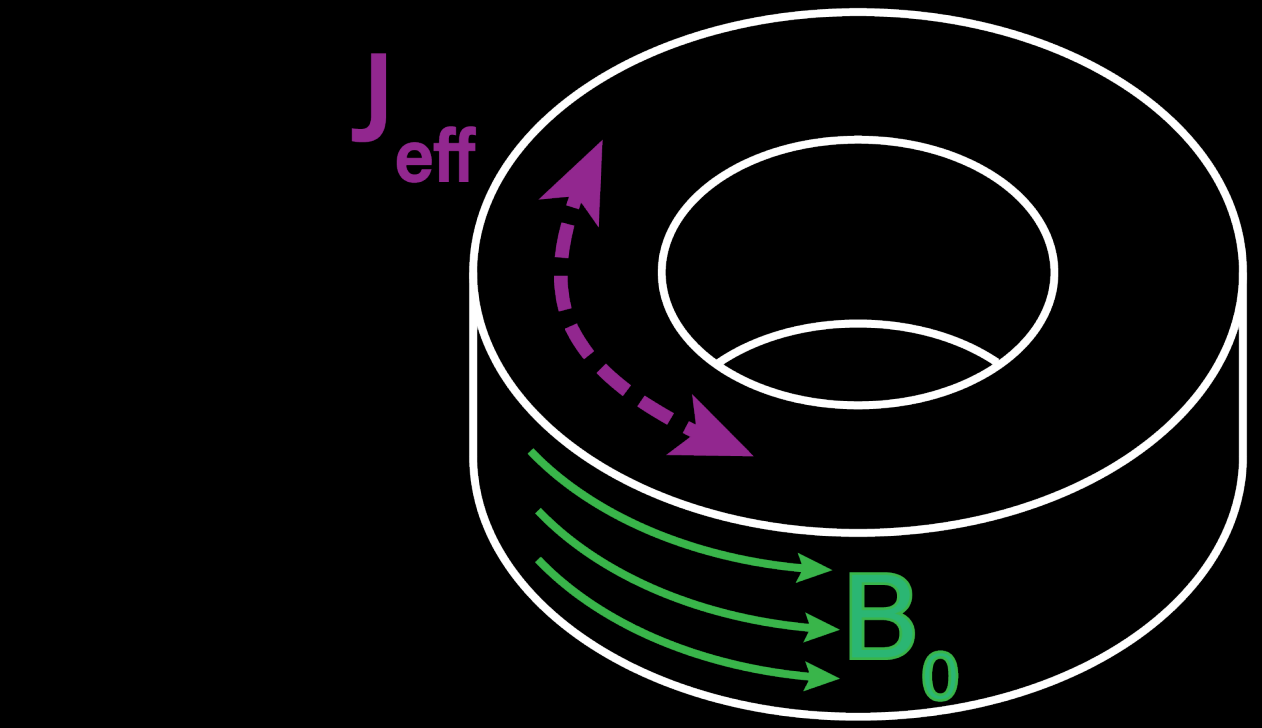
Broadband Approach



$$\vec{J}_{eff} = g_{a\gamma\gamma}\sqrt{2\rho_{DM}}cos(m_a t)\vec{\mathbf{B}}$$

ABRACADABRA

Broadband Approach



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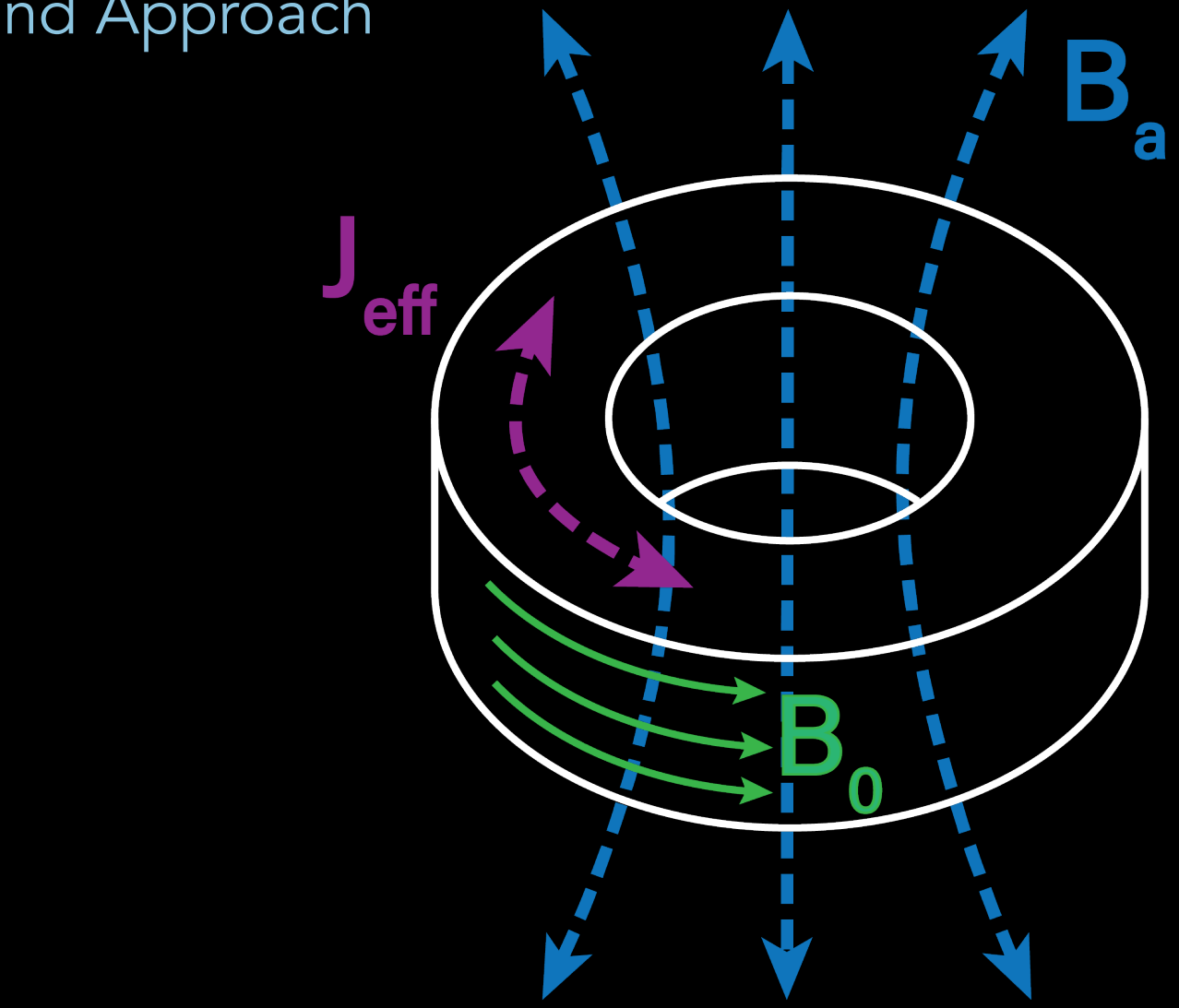
Broadband Approach



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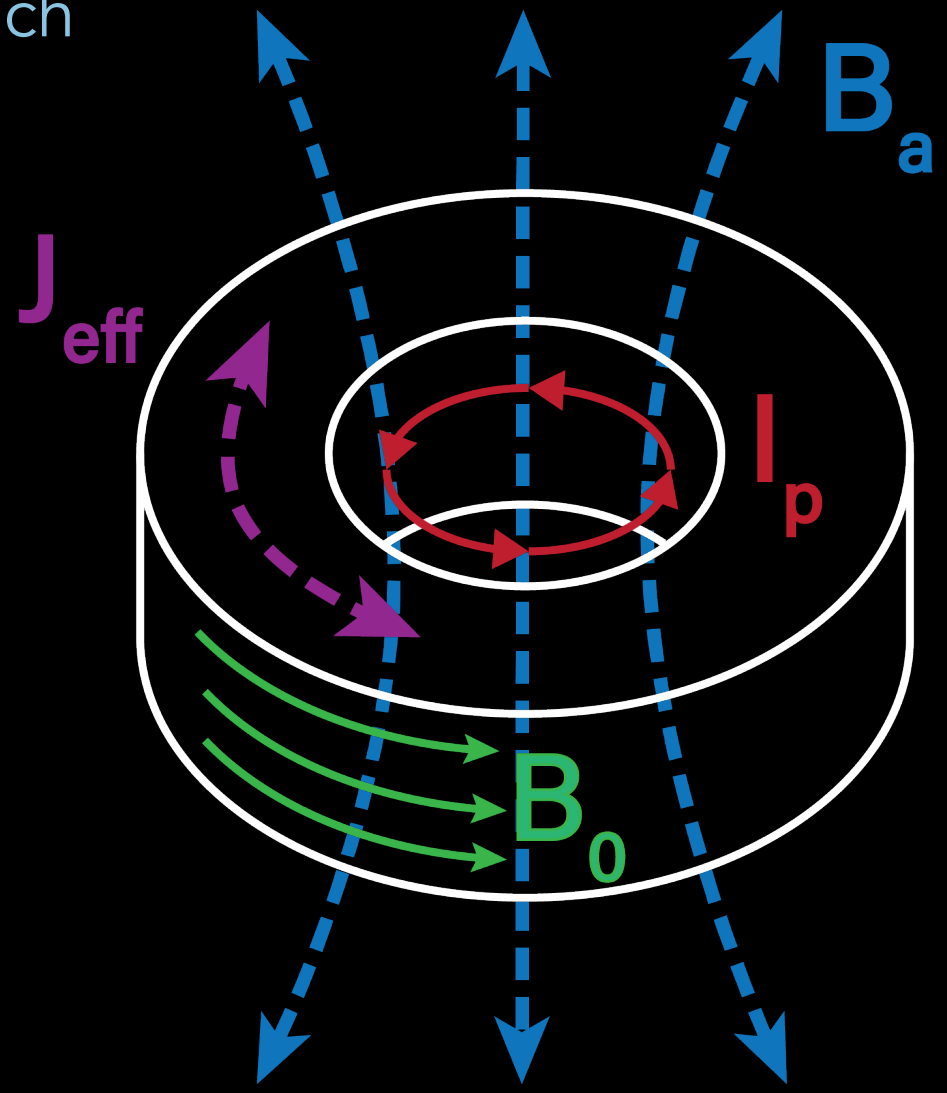
Broadband Approach



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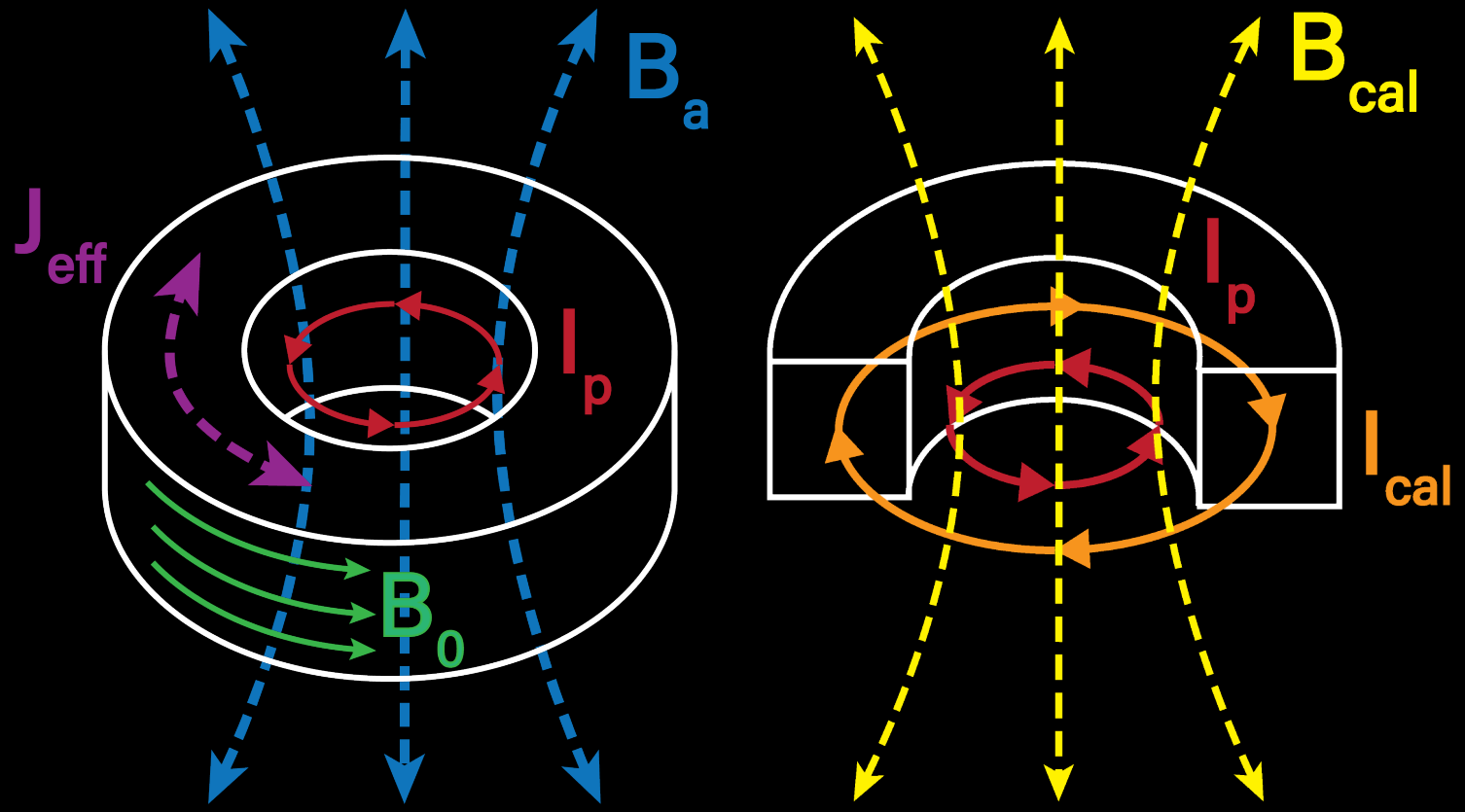
Axion Mimetic Injection

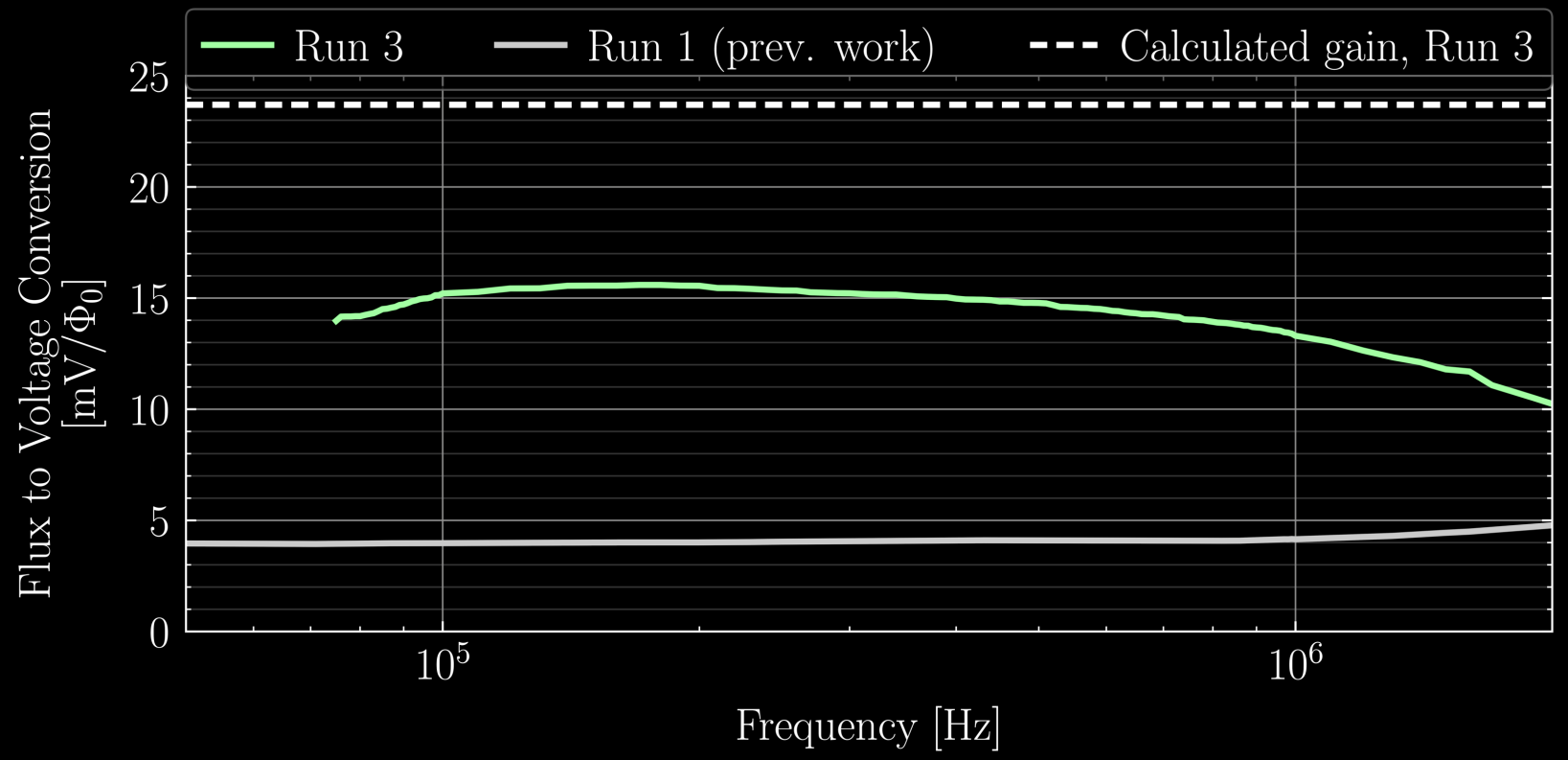


Axion excitation Calibration scheme

Place a calibration loop in the magnet that produces an axion mimetic flux

ABRACADABRA

Axion Mimetic Injection

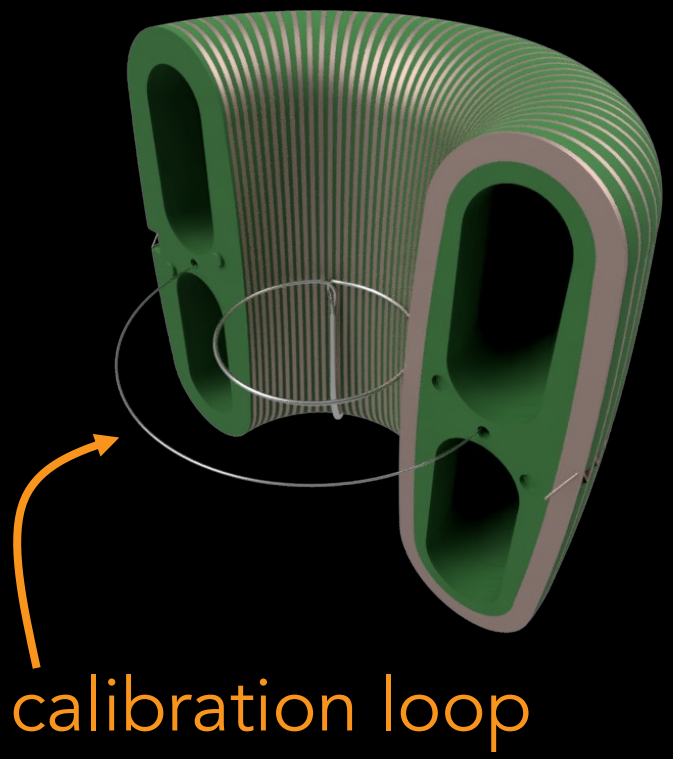


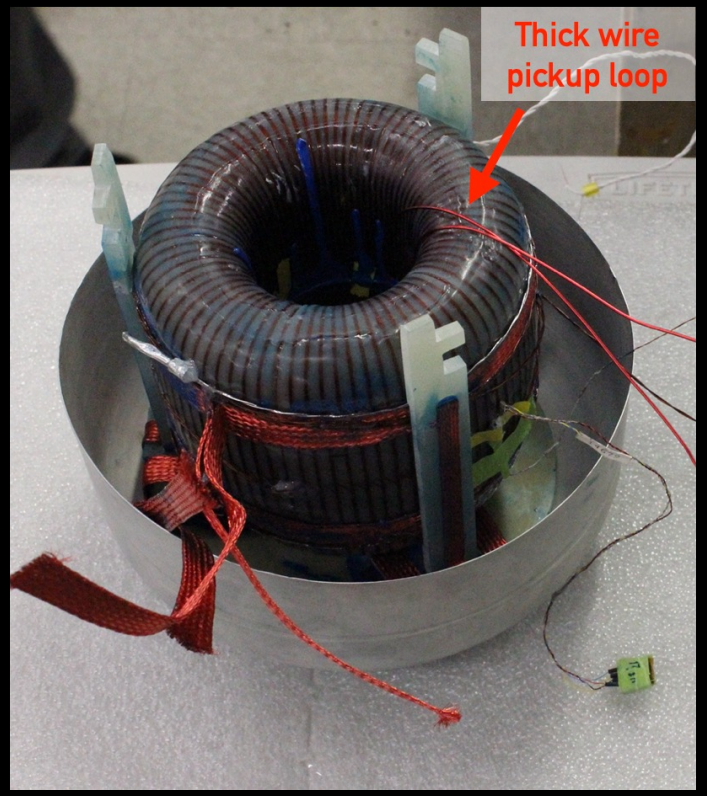
Compare expected gain to measured gain at various frequencies

PhysRevLett.127.081801

ABRACADABRA

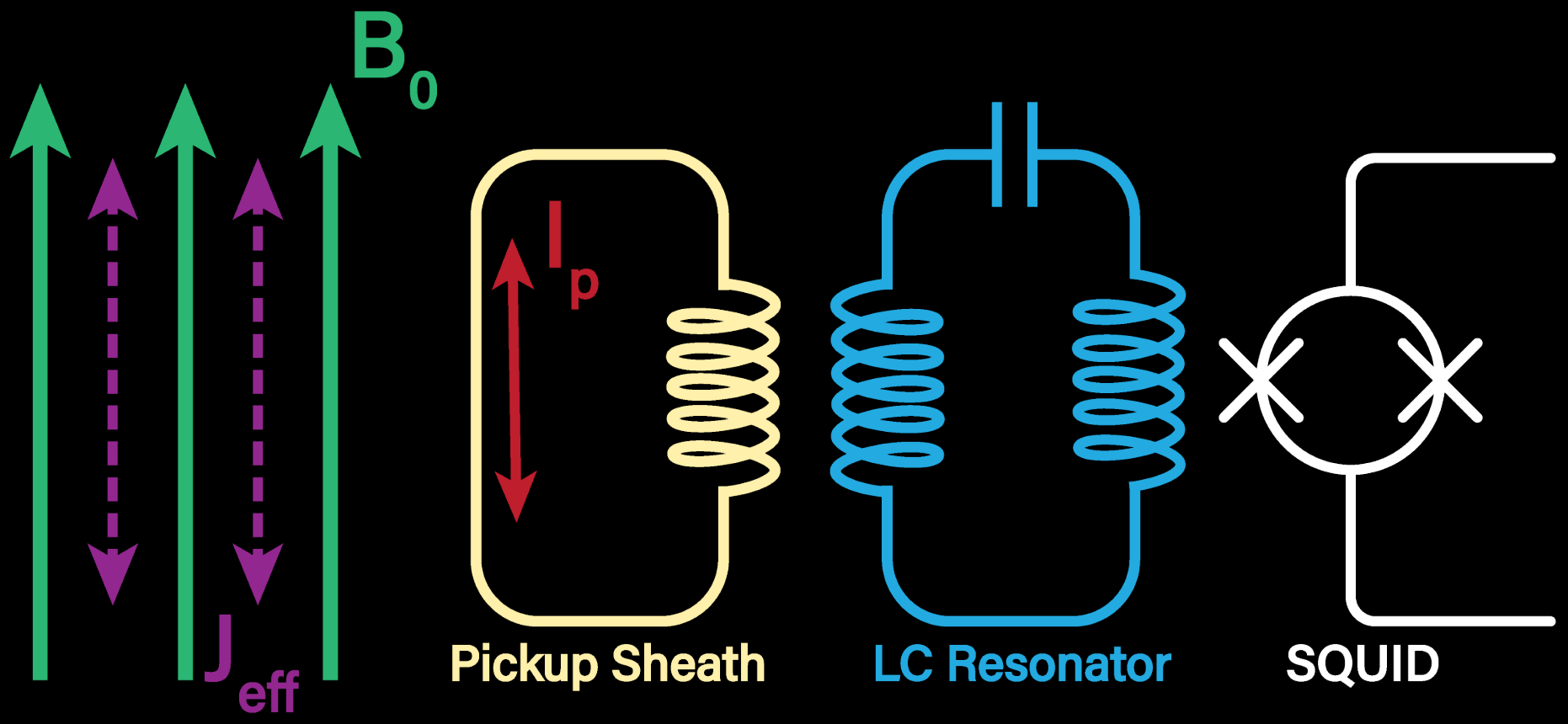
Axion Mimetic Injection





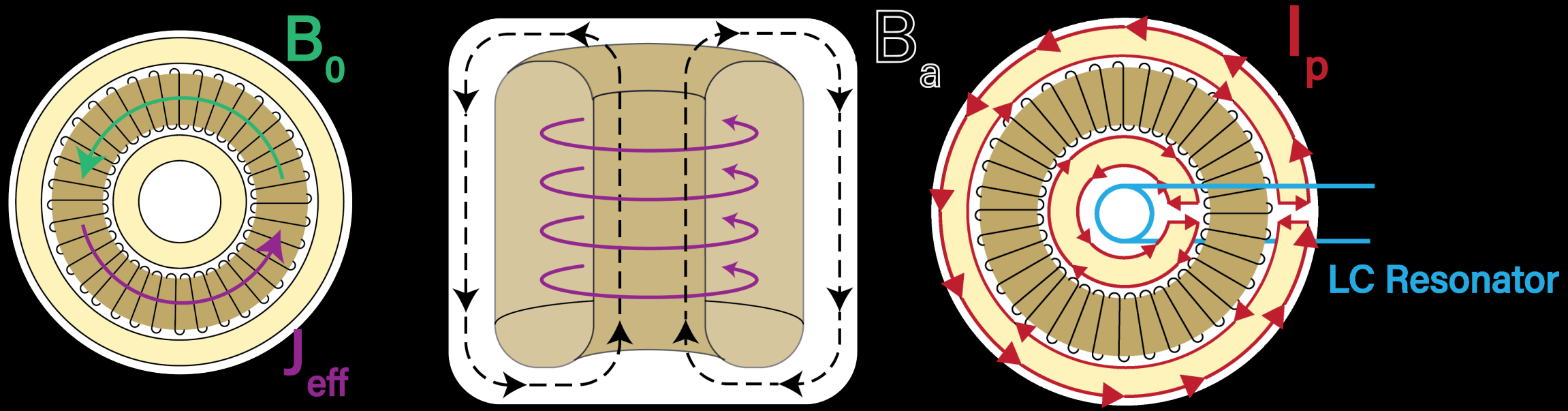
DMRadio

Resonant Approach



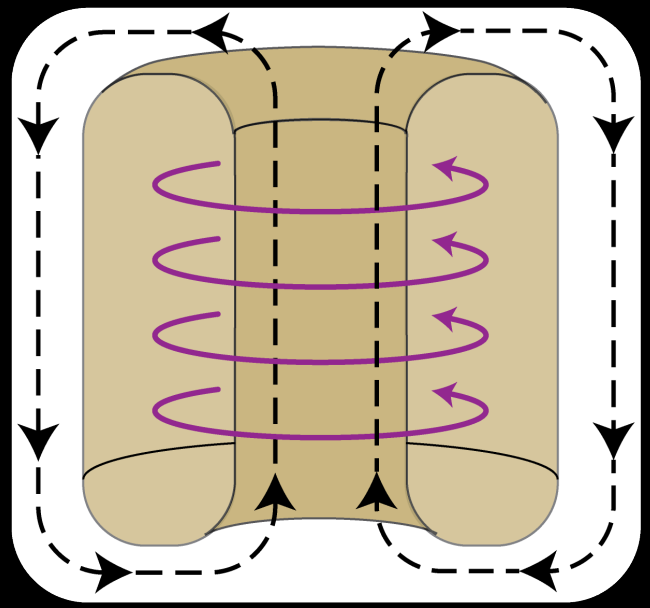
DMRadio-50L

Axion Mimetic Injection

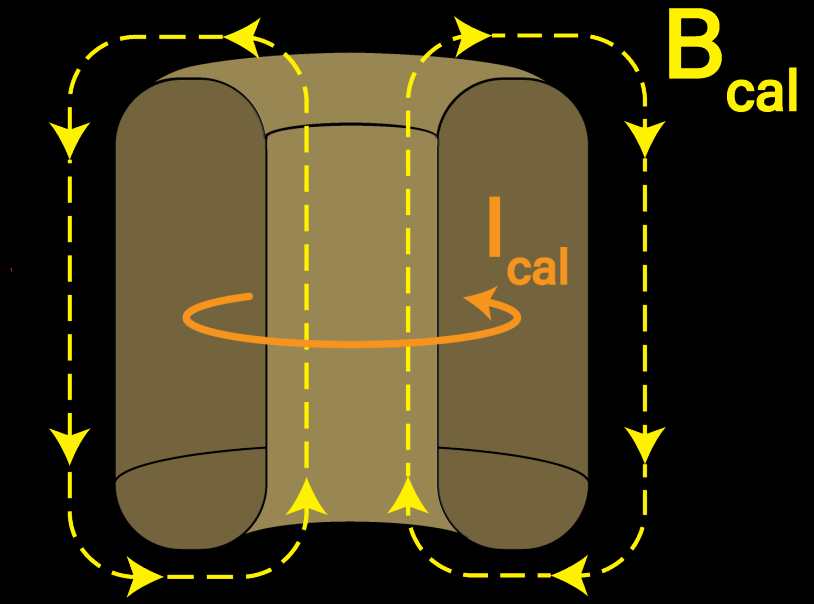


DMRadio-50L

Axion Mimetic Injection



Axion excitation



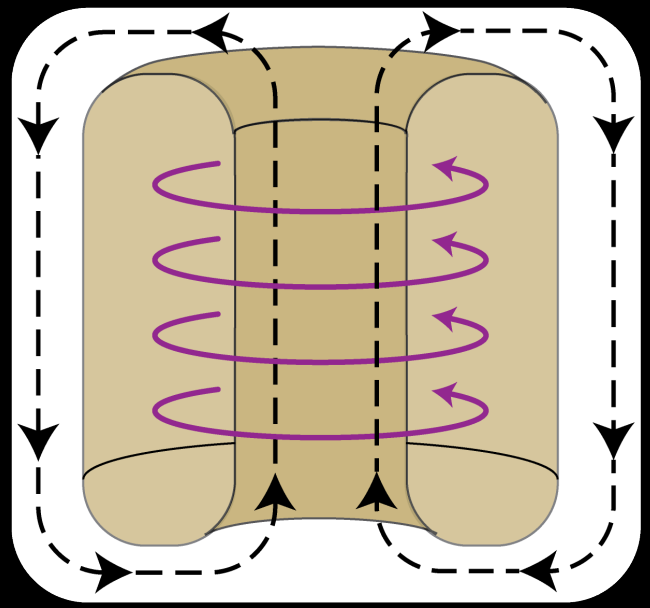
Calibration scheme

Place a calibration loop in the magnet that produces an axion mimetic flux

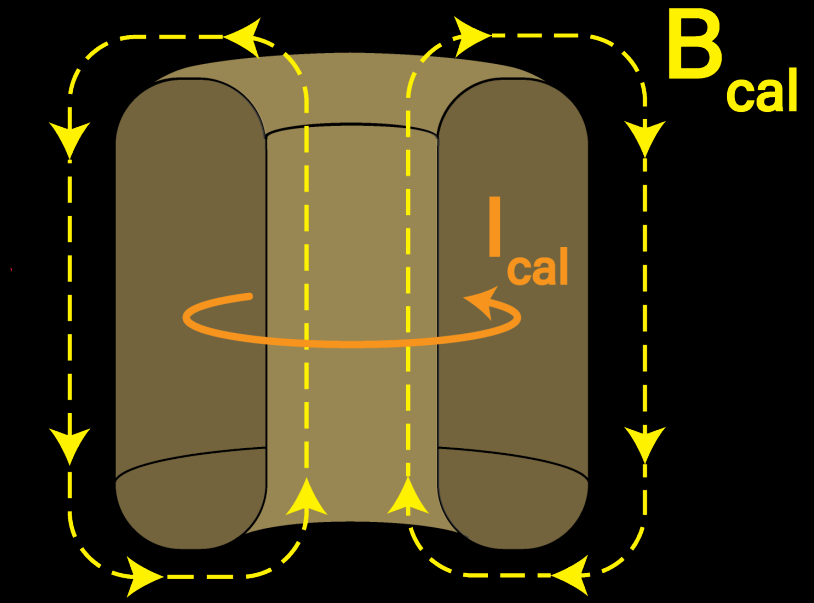
DMRadio-50L

Axion Mimetic Injection

- Magnet enclosed in high Q sheath



Axion excitation



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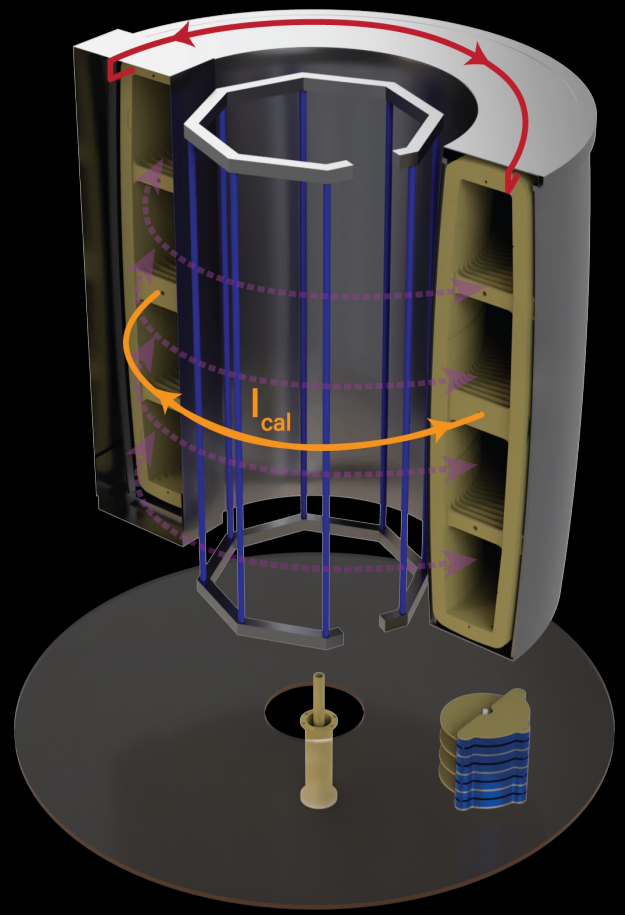
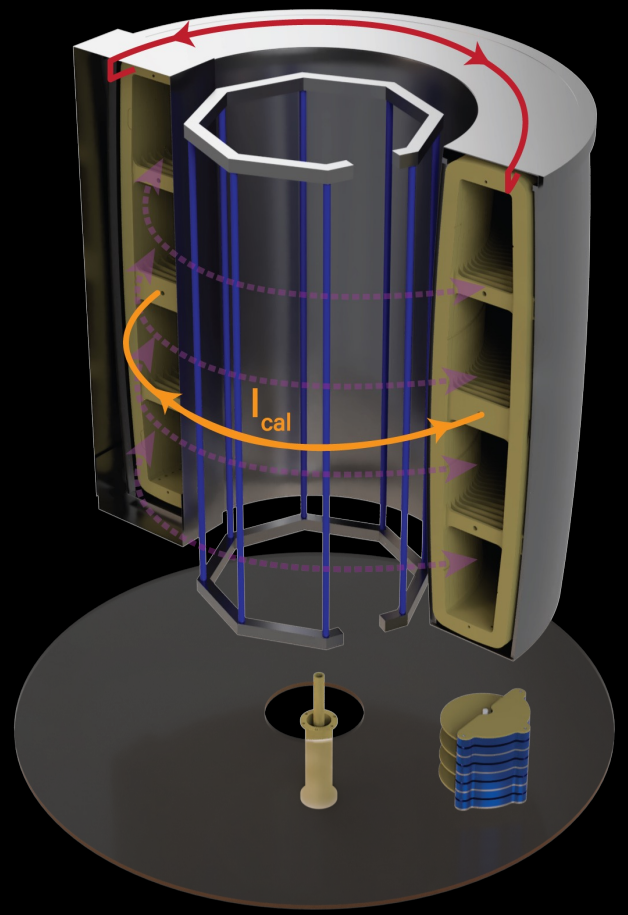


DMRadio-50L

Axion Mimetic Injection

- Magnet enclosed in high Q sheath
- To keep high Q factor, need to minimize conductive toroidal elements
- Cannot take data with axion mimetic loop in detector



Calibration Methods

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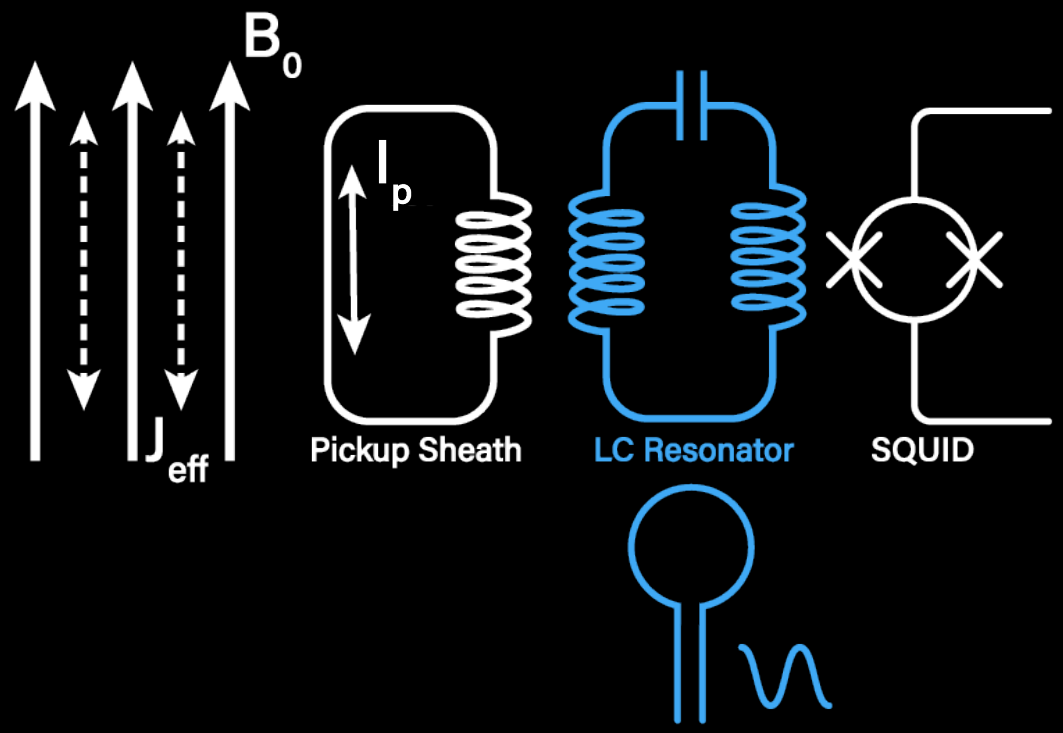
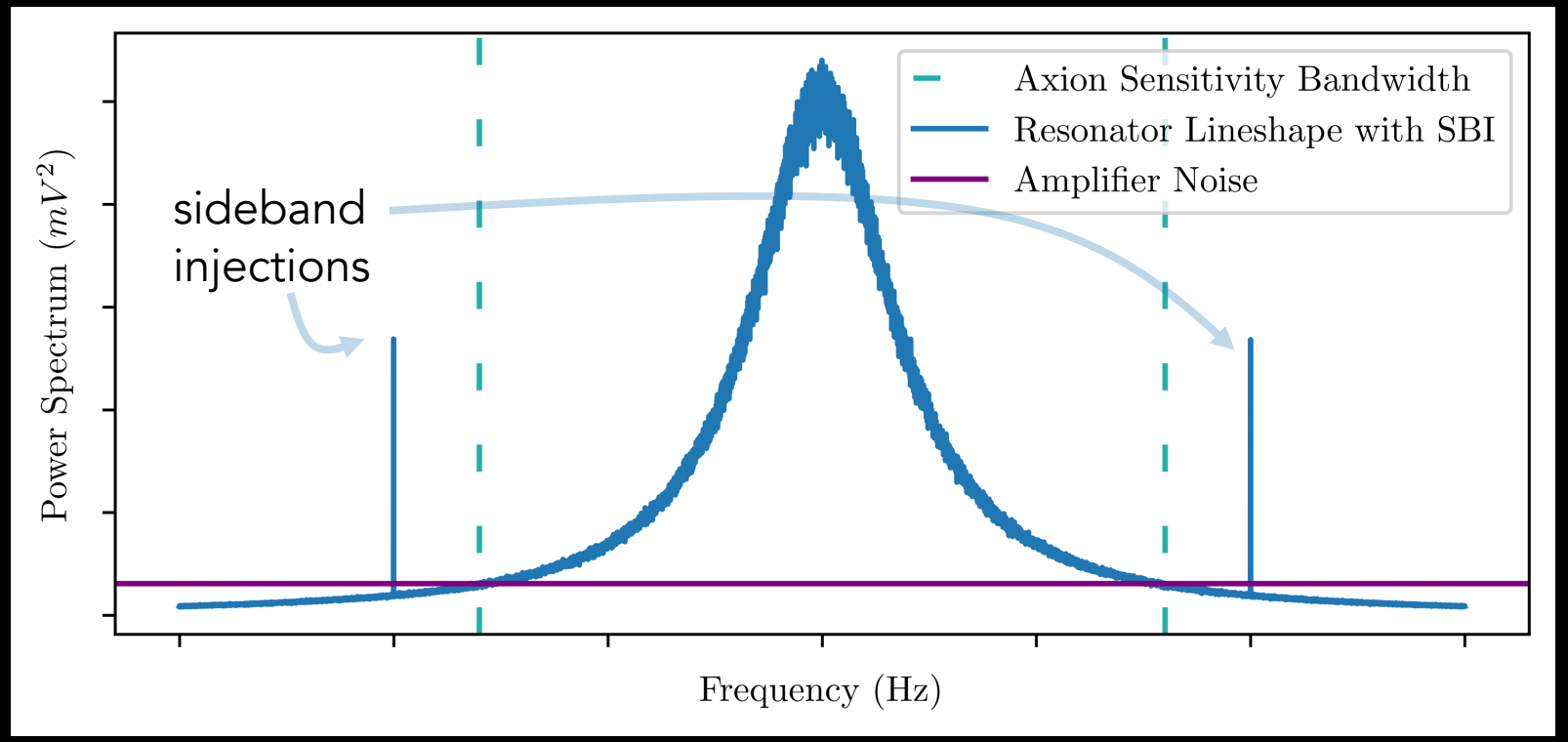
   - Frequency Sweep
   - Ringdown measurement



Sideband Injection

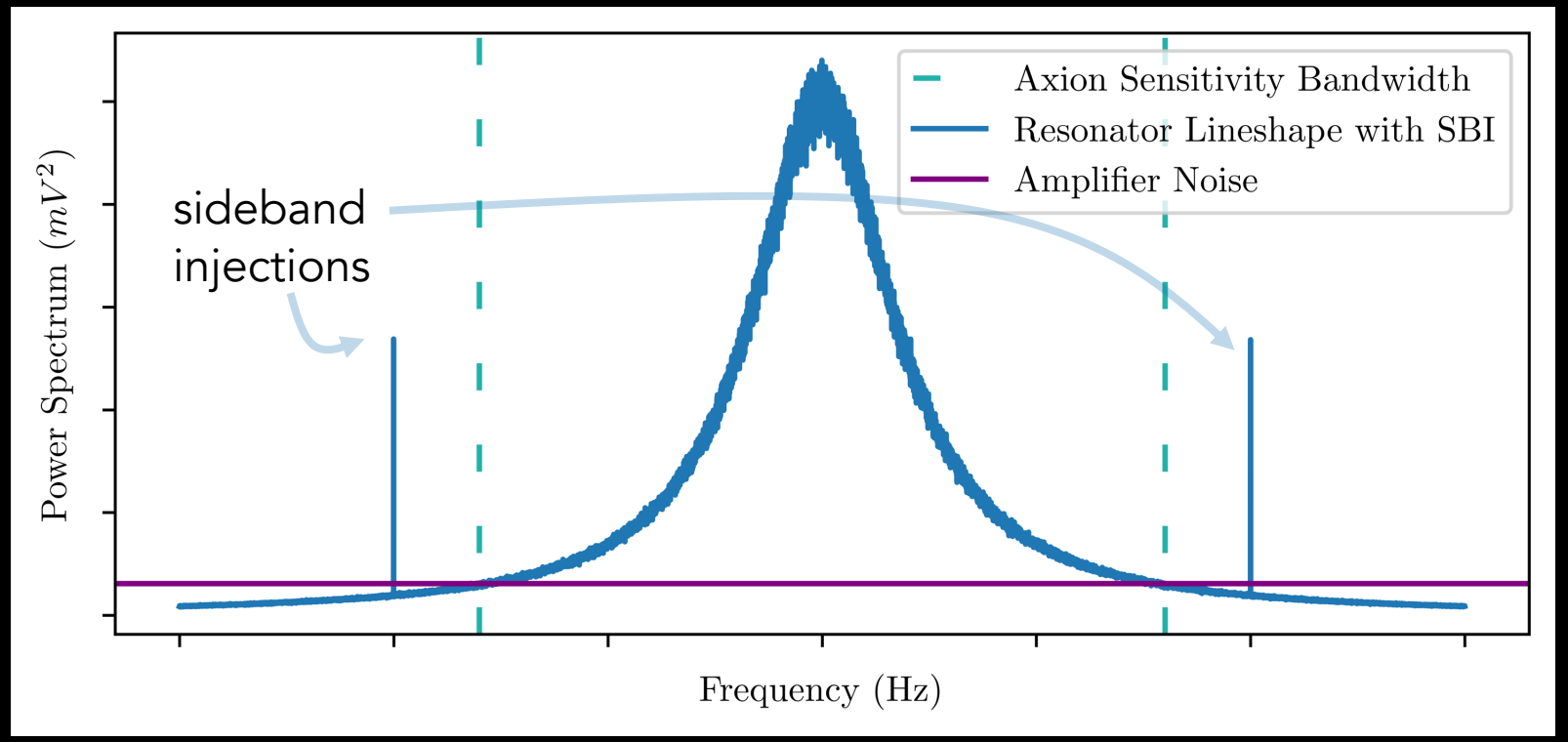
- Inject two monotonic tones outside of axion signal band

$$\left(\frac{\Delta\omega}{\omega}\right)_{AS} = \frac{8}{Q} \qquad \left(\frac{\Delta\omega}{\omega}\right)_{SBI} = \left(\frac{\Delta\omega}{\omega}\right)_{AS} \times \mathrm{frac}_{SBI} = \frac{10}{Q}$$



Sideband Injection

- Compare V_{in}/V_{out} of SBI frequency to get SQUID amplification
- Measure SQUID amplification at each tuning step
- Calibration simultaneous with data taking



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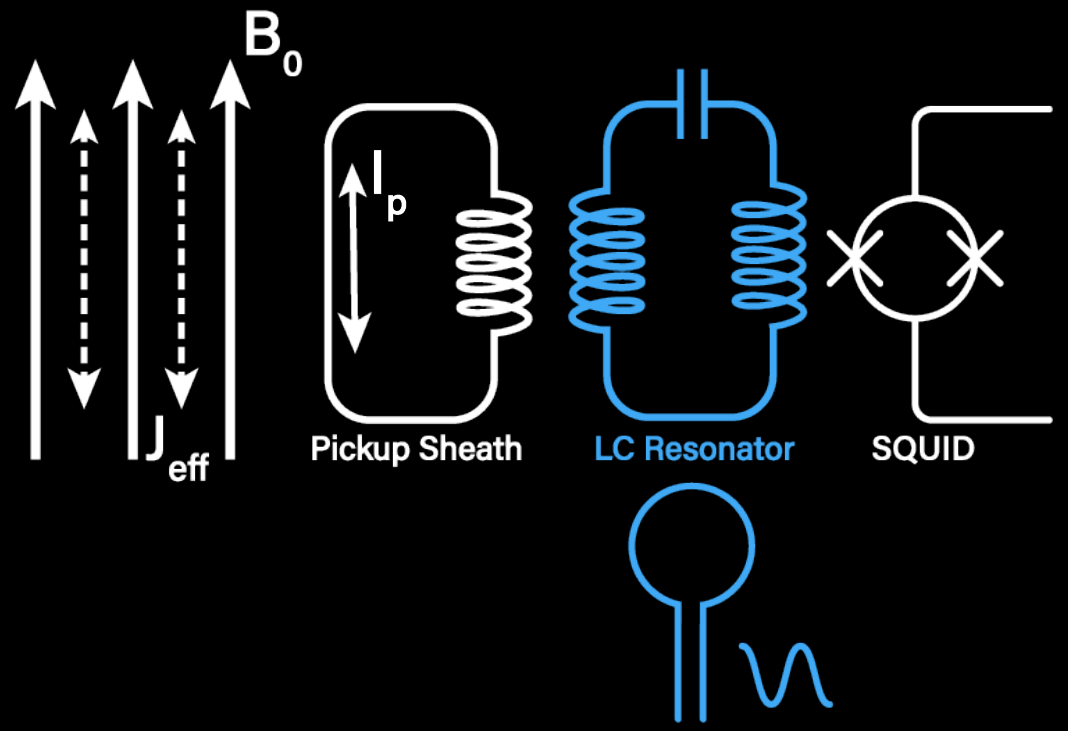
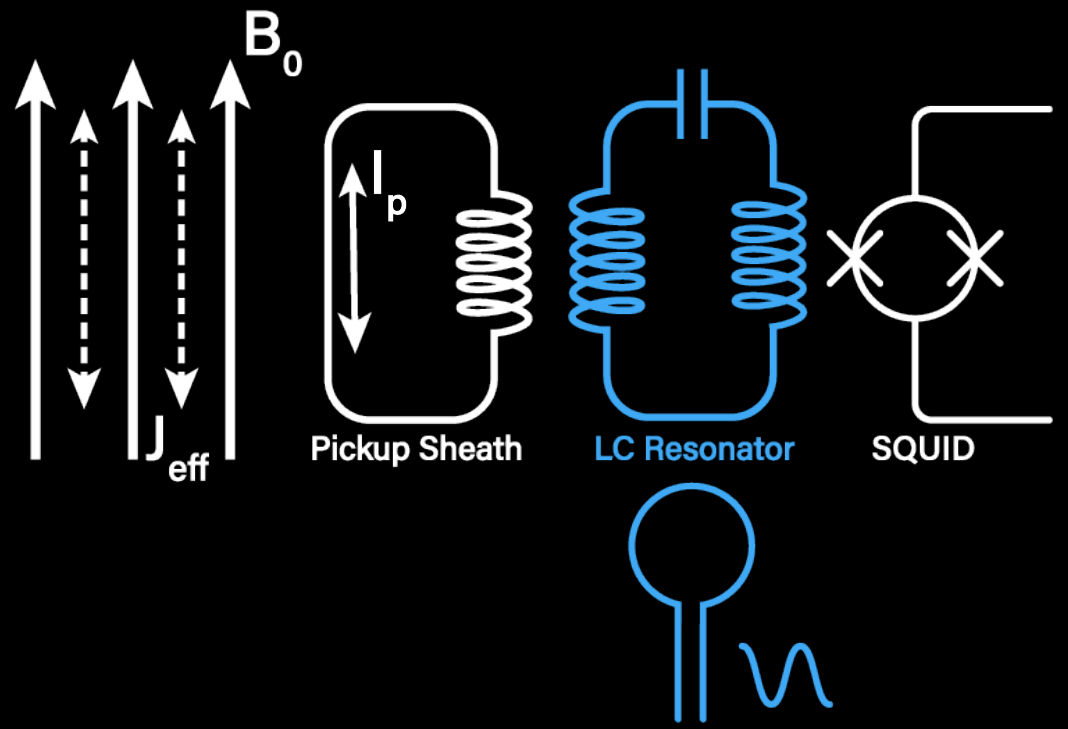


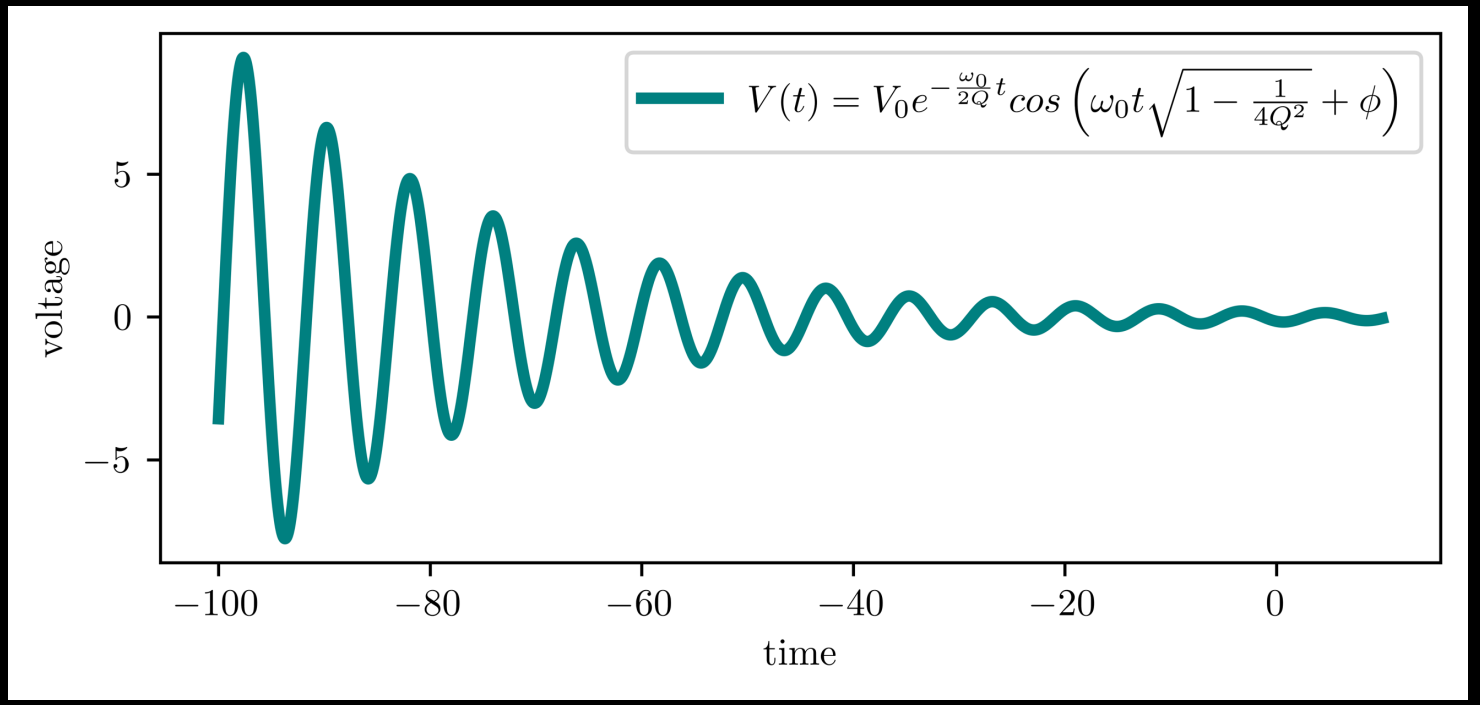
Frequency Sweep & Ringdown

- Couple resonator to wire loop
- Frequency sweep: inject monotonic signal into calibration loop and scan
- Ringdown: inject on-resonance burst into calibration loop



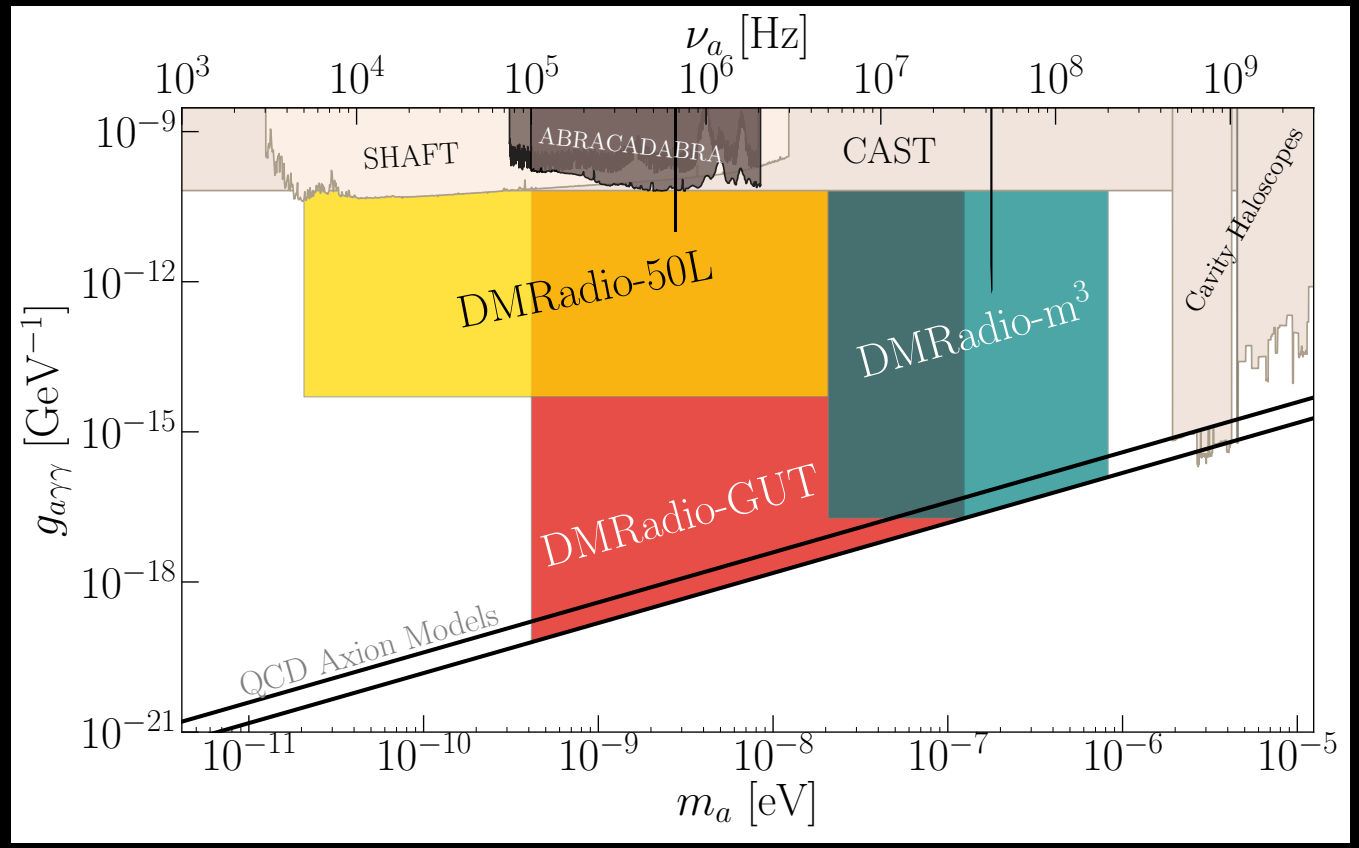
Ringdown Measurement

- Inject on-resonance signal directly onto resonator
- Record free decay
- N_{cycles} to half amplitude gives Q factor and ω_0
- Demonstrated with DMRadio Pathfinder



DMRadio

- Calibrations applicable to all DMRadio experiments
  - Axion mimetic injection
  - Sideband injection
  - Frequency sweep
  - Ringdown measurement



DMRadio Collaboration

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