Axion and high-frequency gravitational wave searches with ABRACADABRA and DMRadio

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Winslow Group

Workshop on Basic Computing Services in the Physics Department - subMIT

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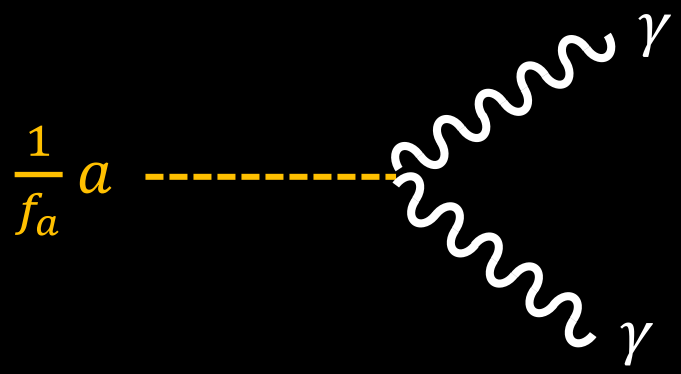
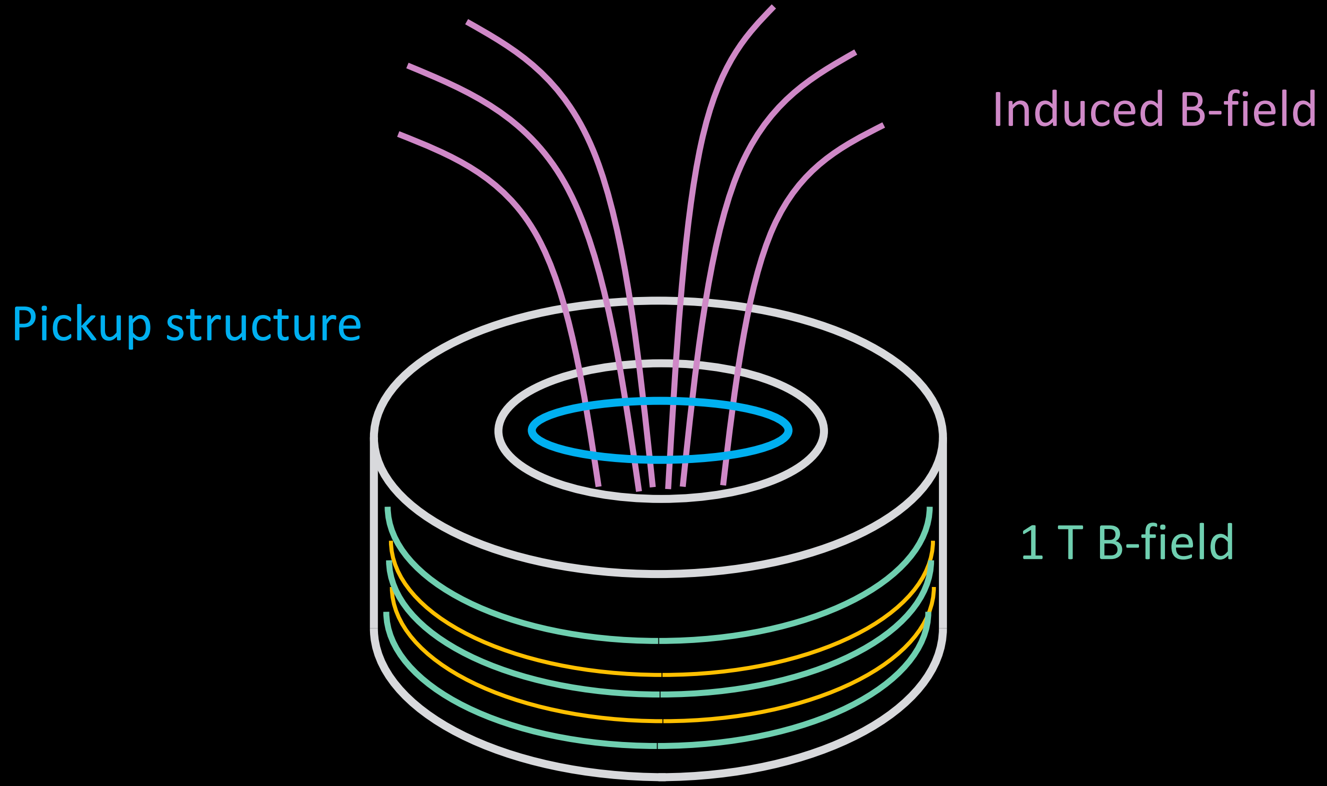
Research purpose

Search for BSM physics using EM interactions

- Low-mass Axions
  - Wave-like DM candidate
- Ultra-high-frequency gravitational waves
  - Produced by primordial black hole mergers

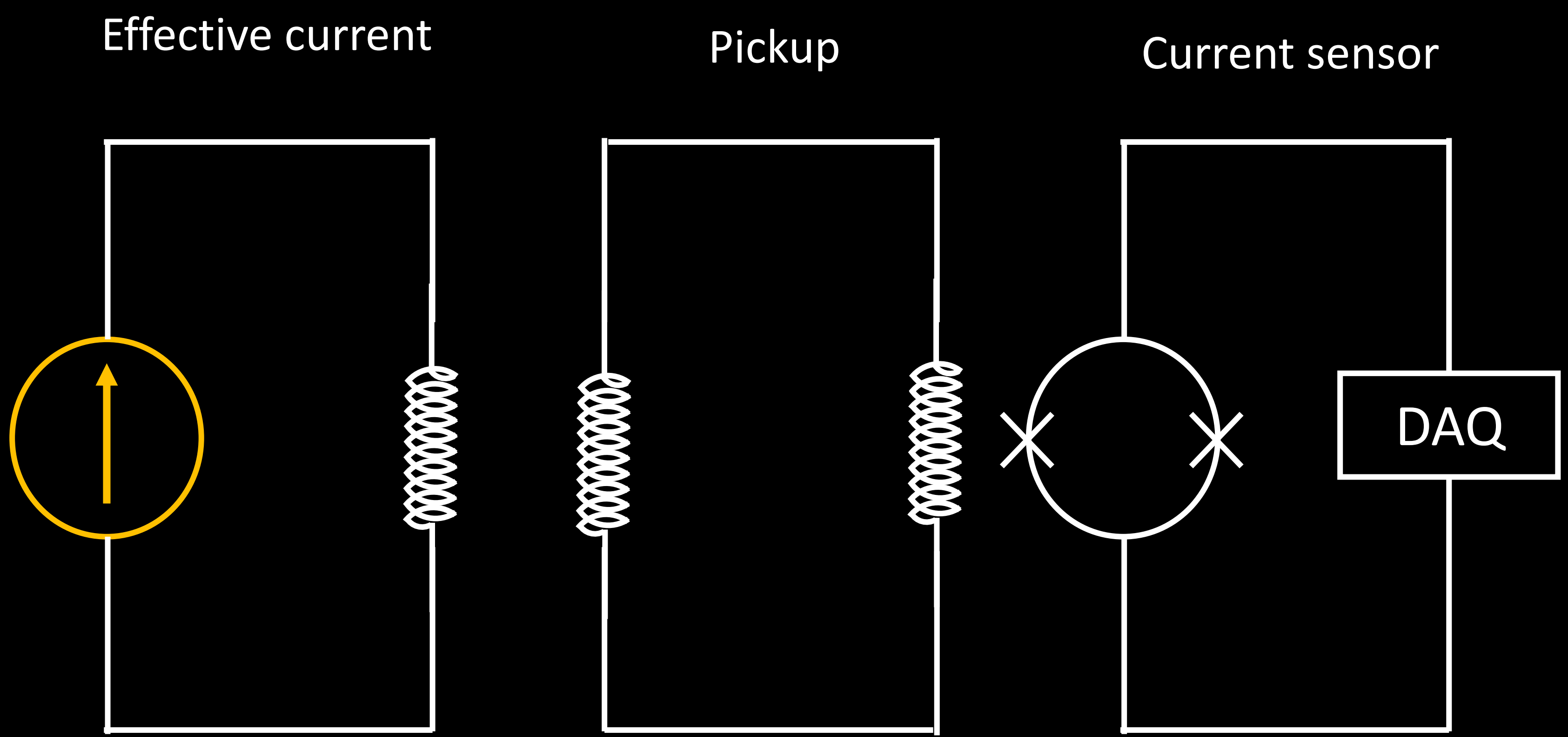


ABRACADABRA-10 cm



$$J_{eff} = g_{a\gamma\gamma}\sqrt{\rho_{DM}}\cos(m_a t)B$$

Lumped element searches



Axion Signal

Gauss-Ampère law

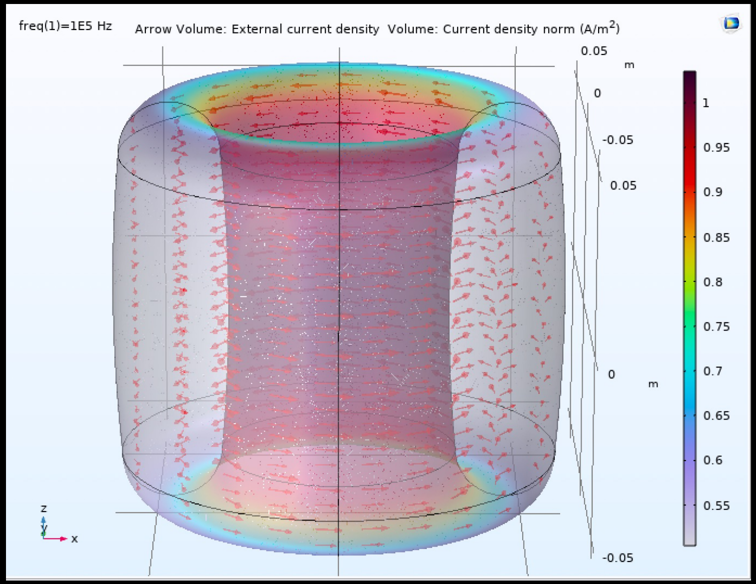
$$\partial_\nu F^{\mu\nu} = j^\mu_{eff}$$

Axions Modification:

$$j^\mu_{eff} = \partial_\nu\left(g_{a\gamma\gamma} a \tilde{F}^{\nu\mu}\right)$$

$$\downarrow$$

$$J_{eff} = g_{a\gamma\gamma}\sqrt{\rho_{DM}}\cos(m_a t)B$$

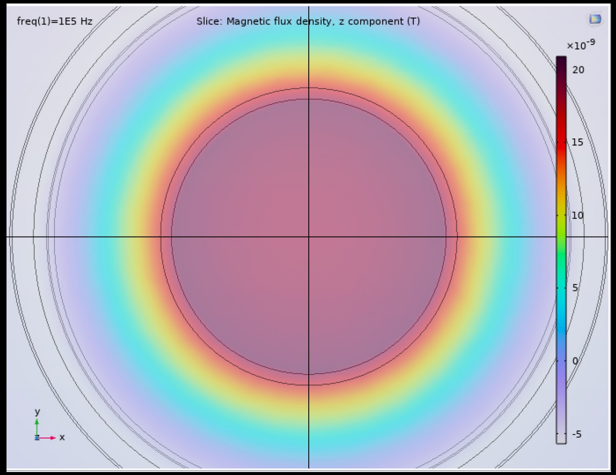


Axion effective current in the ABRA magnetic volume

Axion Signal

Gauss-Ampère law

$$\partial_\nu F^{\mu\nu} = j^\mu_{eff}$$



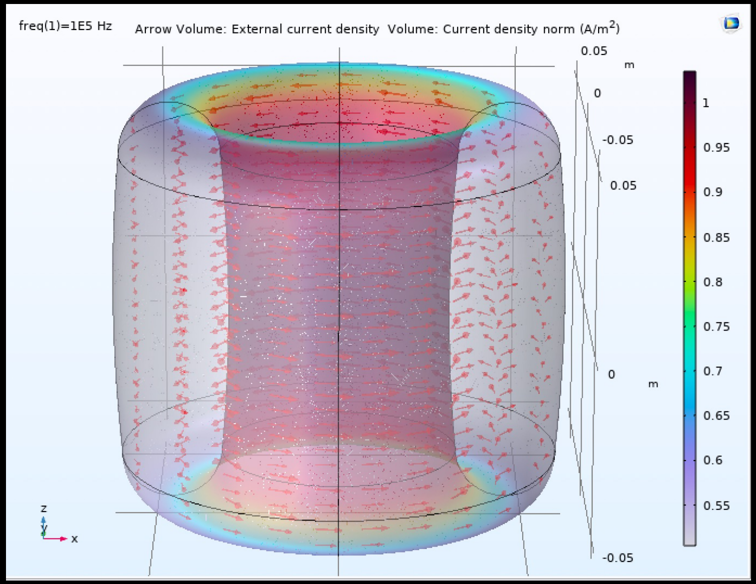
The z-component of the magnetic field resulting from an axion effective current

Axions Modification:

$$j^\mu_{eff} = \partial_\nu \left(g_{a\gamma\gamma} a \tilde{F}^{\nu\mu} \right)$$

$$\downarrow$$

$$J_{eff} = g_{a\gamma\gamma} \sqrt{\rho_{DM}} \cos(m_a t) B$$



Axion effective current in the ABRA magnetic volume

Gravitational Wave Signal

Gauss-Ampère law

$$\partial_\nu F^{\mu\nu} = j^\mu_{eff}$$

Gravitational Wave Modification:

$$j^\mu_{eff} = \partial_\nu \left(-\frac{1}{2} h F^{\mu\nu} + F^{\mu\alpha} h^\nu_\alpha - F^{\mu\nu} h^\mu_\alpha \right)$$

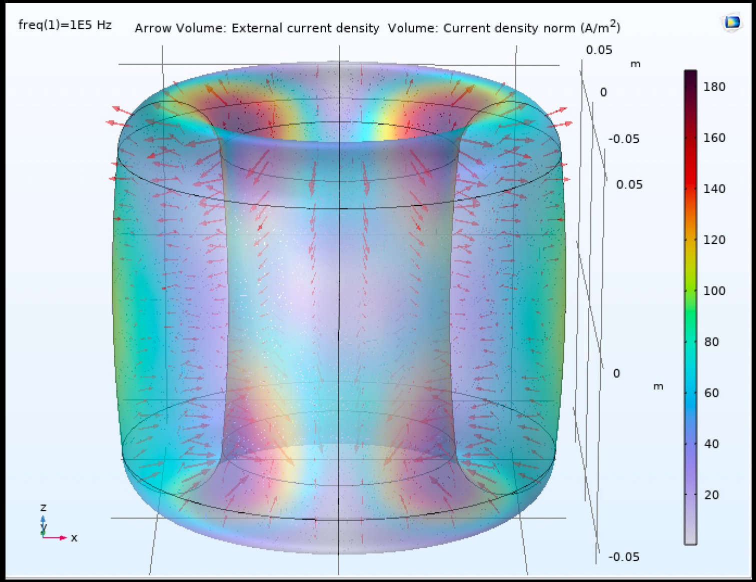
Gravitational Wave Signal

Gauss-Ampère law

$$\partial_\nu F^{\mu\nu} = j^{\mu}_{eff}$$

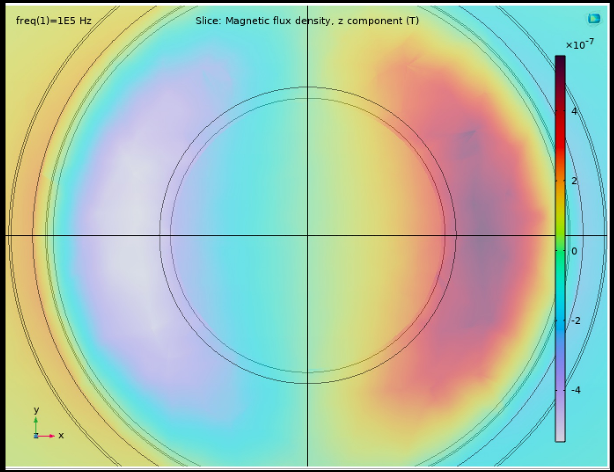
Gravitational Wave Modification:

$$j^{\mu}_{eff} = \partial_\nu \left(-\frac{1}{2} h F^{\mu\nu} + F^{\mu\alpha} h^{\nu}_{\alpha} - F^{\mu\nu} h^{\mu}_{\alpha} \right)$$



GW effective current in the ABRA magnetic volume

Gravitational Wave Signal



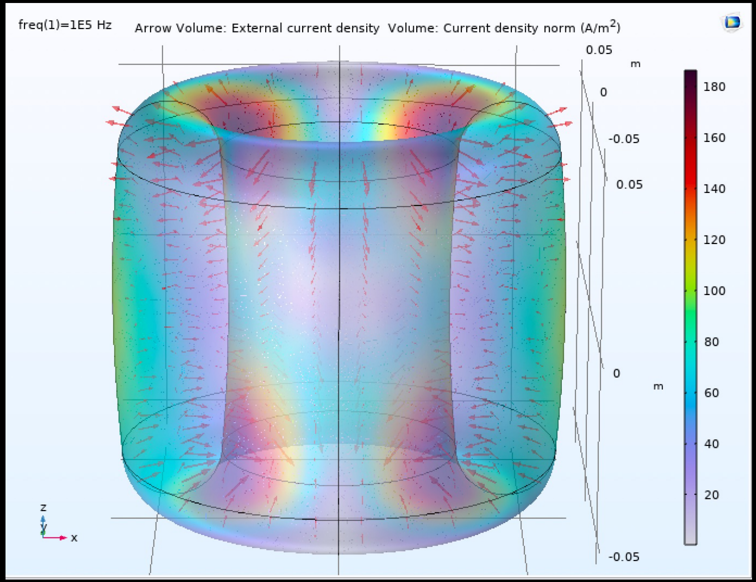
The z-component of the magnetic field resulting from a GW effective current

Gauss-Ampère law

$$\partial_\nu F^{\mu\nu} = j^\mu_{eff}$$

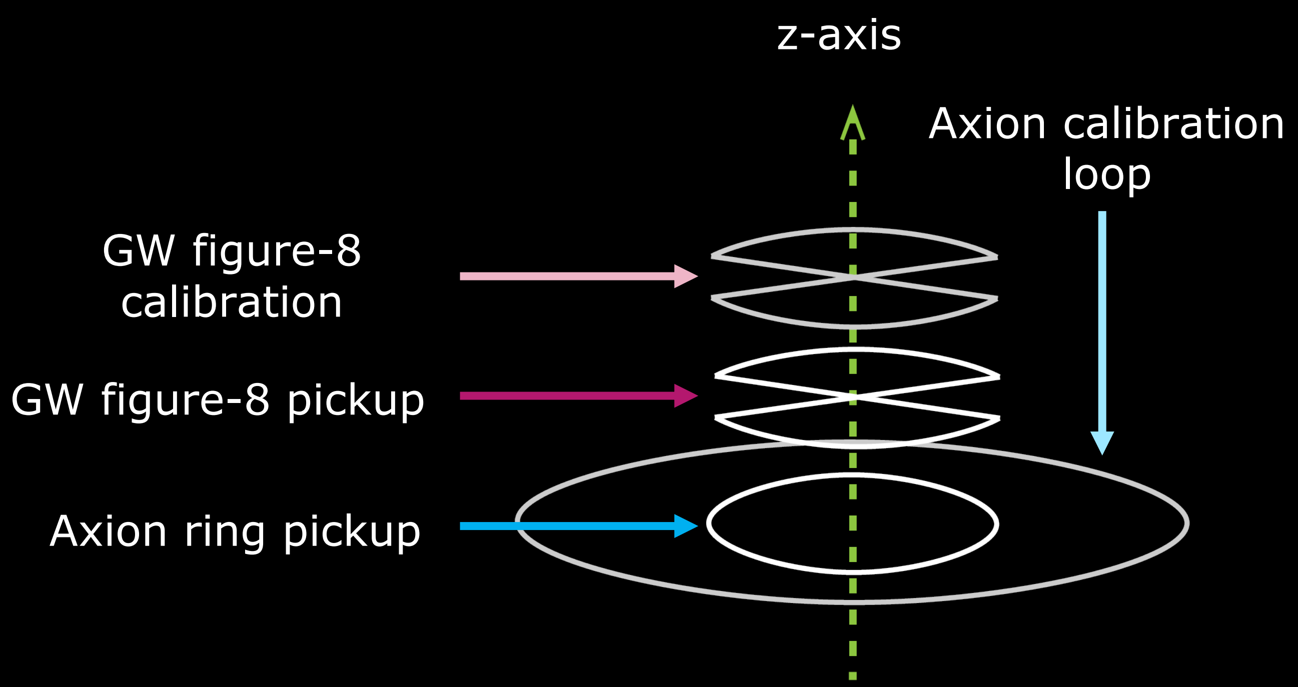
Gravitational Wave Modification:

$$j^\mu_{eff} = \partial_\nu \left(-\frac{1}{2} h F^{\mu\nu} + F^{\mu\alpha} h^\nu_\alpha - F^{\mu\nu} h^\mu_\alpha \right)$$

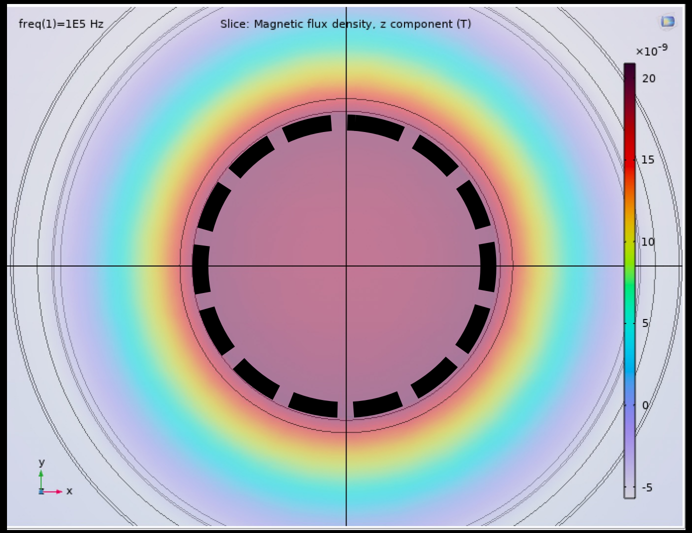


GW effective current in the ABRA magnetic volume

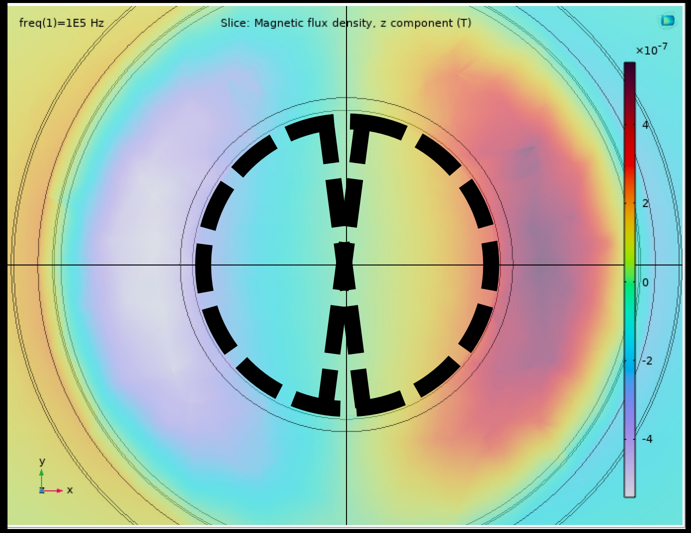
Experimental Setup



The pickup structures and calibration structures that are used in the GW axion run

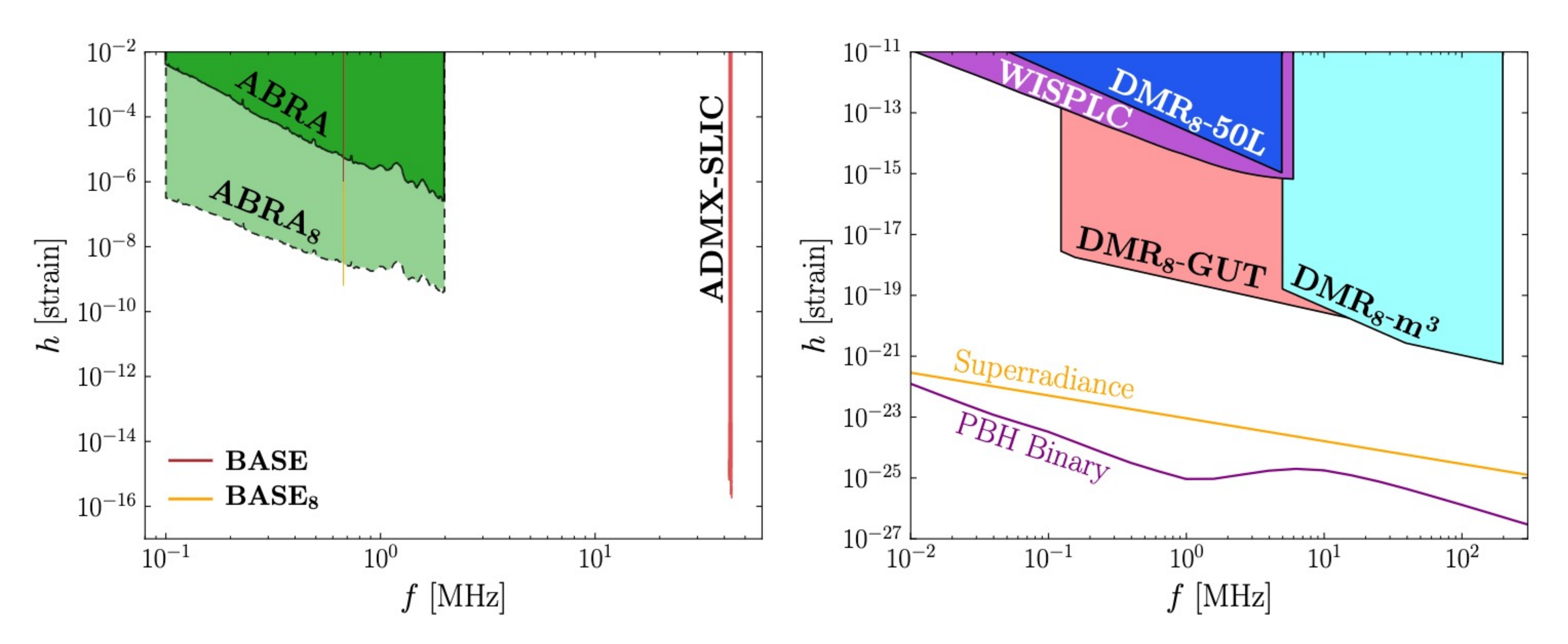


The z-component of the magnetic field resulting from an axion effective current



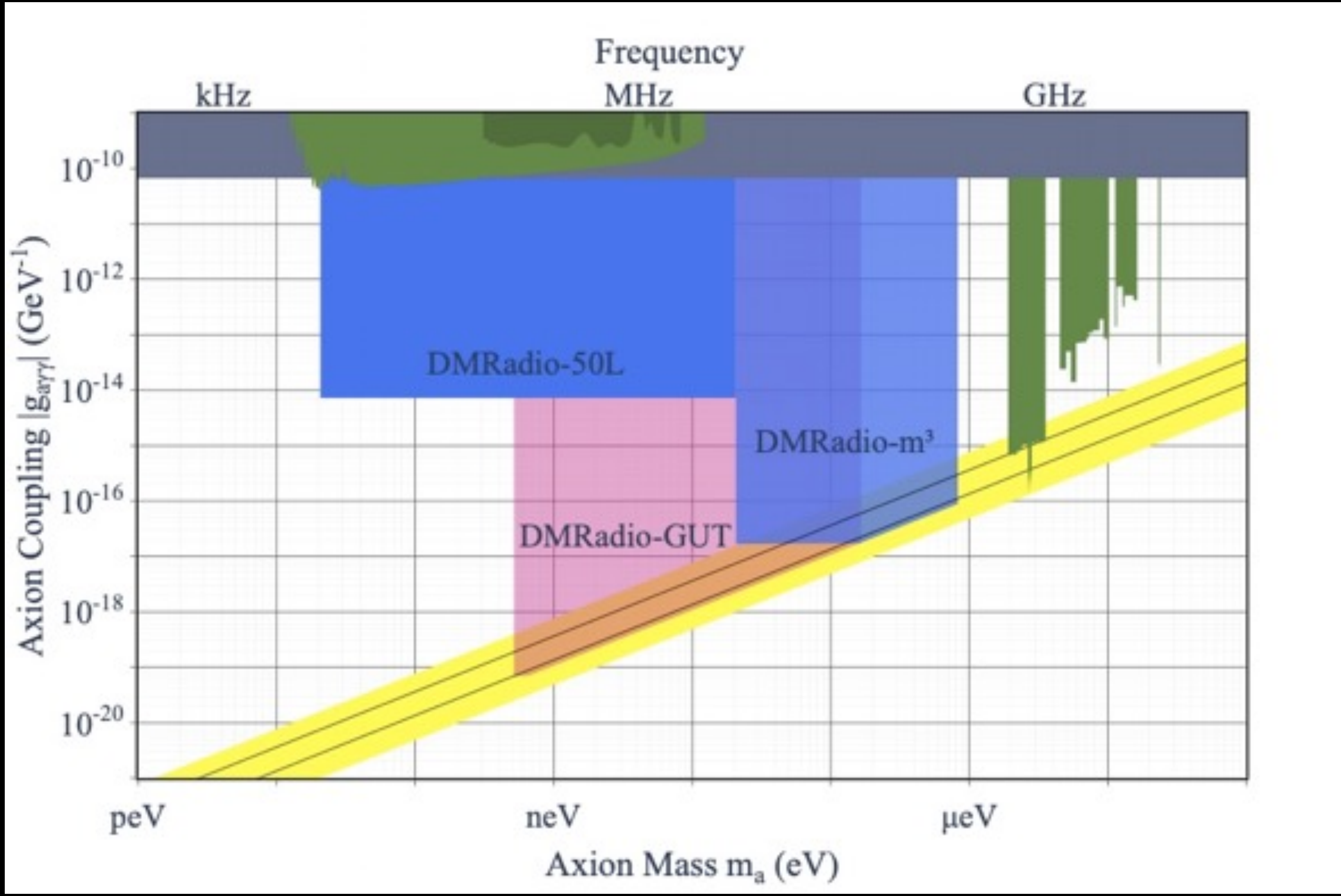
The z-component of the magnetic field resulting from a GW effective current

Projected sensitivity

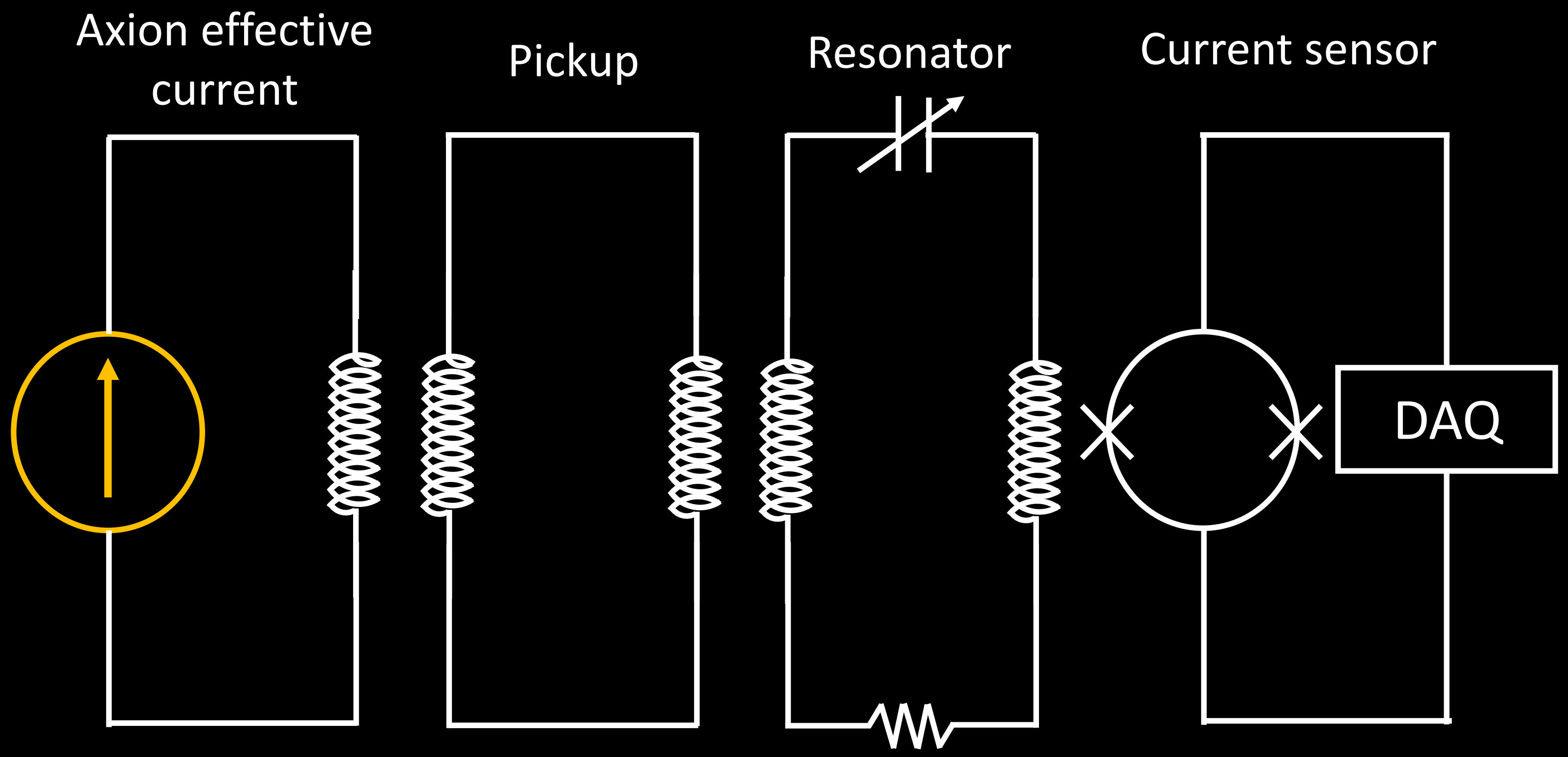


arXiv:2306.03125

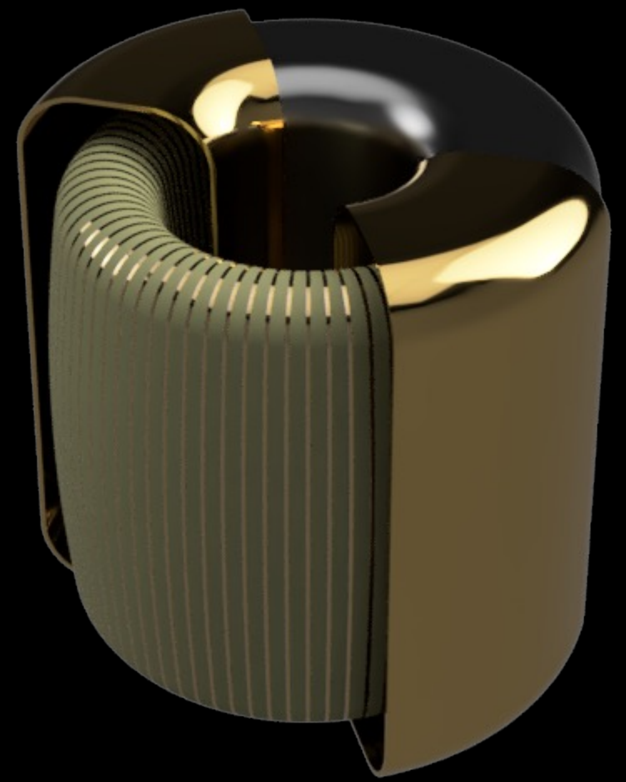
DMRadio projected sensitivity



DMRadio 50 L



Axion effective current
Pickup
Resonator
Current sensor
DAQ



Experimental status

ABRA-GW:

All data collected, analysis pipeline in progress

DMRadio 50L:

In construction, first data end of 2024

SubMIT usage

Storage for DMRadio 50L and ABRACADABRA data

- The group has purchased 5 Western Digital 18TB Red Pro SATA 6Gb s 3.5” Internal Hard Drives
- Current and past ABRA runs (~20 TBs of data)
- Future DMRadio 50L data (unknown, probably ~TBs)

Run History and Data Storage

Run #	Data size	Current data location*	Analysis location
Run 1 (axion data) DOI: 10.1103/PhysRevLett.122.121802	~ 4 T	U Michigan Cluster and subMIT	U Michigan Cluster
Run 2 (axion data)	~ 4 T	U Michigan Cluster, Berkeley Cluster and subMIT	Berkeley Cluster
Run 3 (axion data) DOI: 10.1103/PhysRevLett.127.081801	4.0 T	Berkeley Cluster and subMIT	Berkeley Cluster
Run 4 (noise data)	3.0 T	SubMIT	Local computer + SubMIT
Run 5 (noise data)	3.2 T	SubMIT	Local computer + SubMIT
Run 6 (GW data)	7.7 T	SubMIT	SubMIT

*With the exception of Run 6 fully, all runs are also backed up on external hard drives

SubMIT usage

ABRA analysis

- Signal filtering (switching between the time and frequency domains)
- Template searching (optimal filtering)
- Using jupyter-notebooks for small data testing
- Will use batch jobs for full analysis

ABRACADABRA Collaboration

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