Massachusetts Institute of Technology

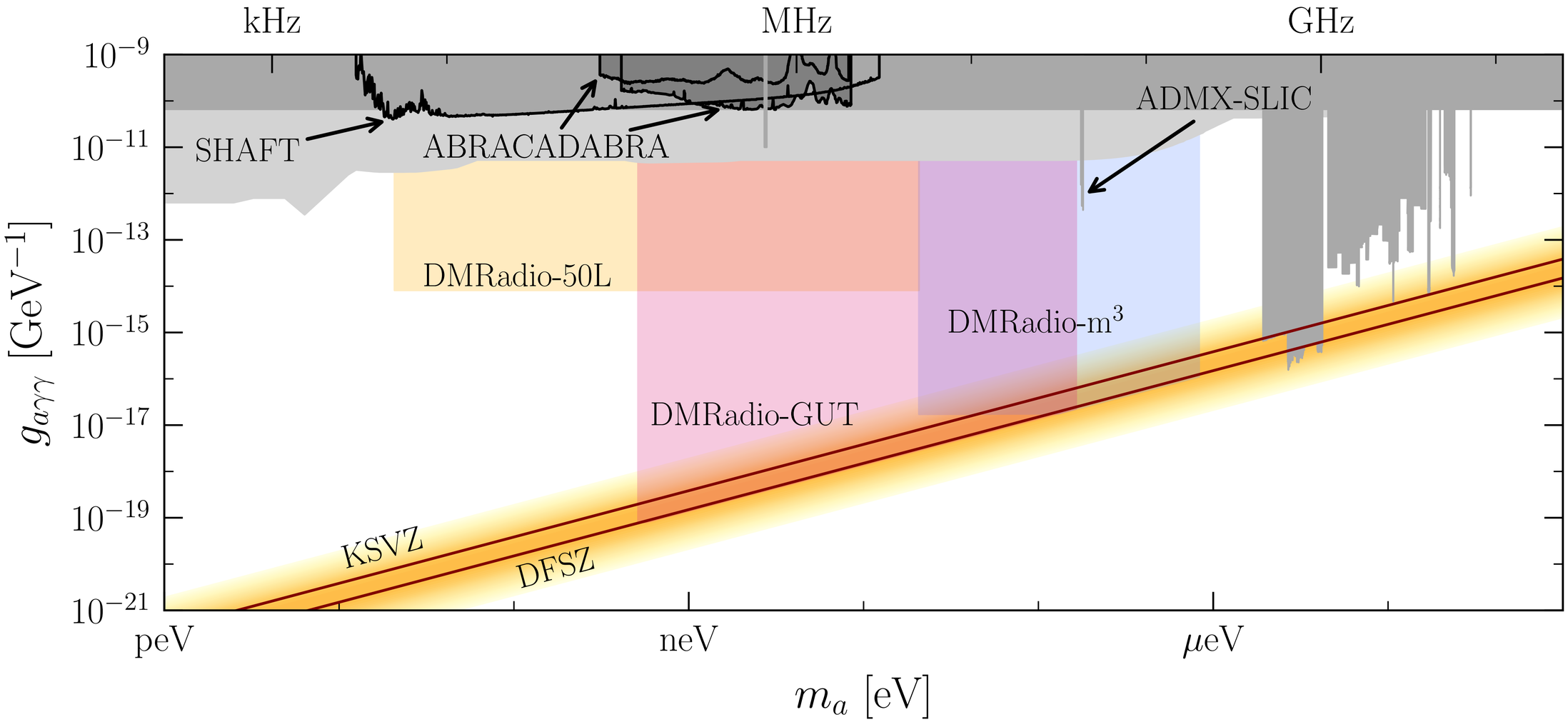
LUMPED ELEMENT AXION DETECTION AT ALL FREQUENCIES

Joshua W. Foster

MIT Center for Theoretical Physics

April 16, 2024

THE DMRADIO EXPERIMENTAL PROGRAM



J.F. + DMRadio Collaboration arXiv:2204.13781 [hep-ex]

LUMPED ELEMENT AXION DETECTION

ABRACADABRA

$$\mathcal{L}_{\mathrm{EM}} \supset -\frac{1}{4}FF - \frac{1}{4}g_{a\gamma\gamma}aF\tilde{F}$$

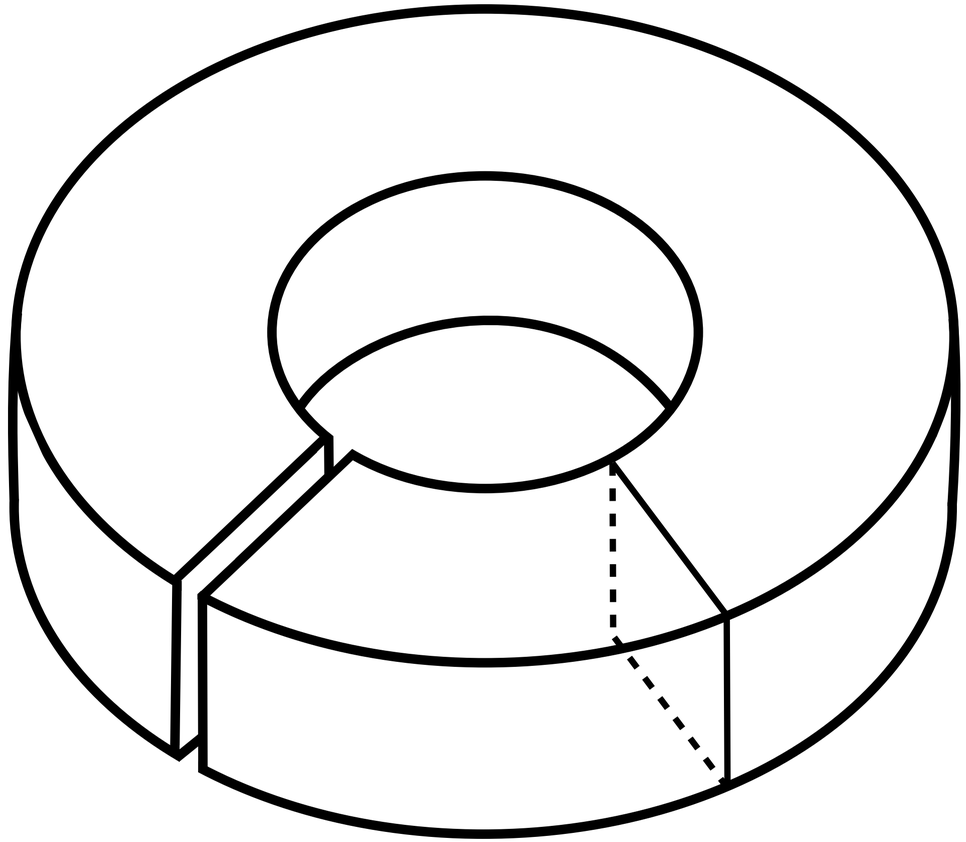
Modified Maxwell's Equations

$$\boldsymbol{\nabla}\cdot\mathbf{E} = \rho - g_{a\gamma\gamma}\mathbf{B}\cdot\boldsymbol{\nabla}a$$

$$\boldsymbol{\nabla}\times\mathbf{B} = \dot{\mathbf{E}} + \mathbf{J} - g_{a\gamma\gamma}\left(\mathbf{E}\times\boldsymbol{\nabla}a - \dot{a}\mathbf{B}\right)$$

Cold DM limit

$$\boldsymbol{\nabla}\times\mathbf{B} = \dot{\mathbf{E}} + \mathbf{J} + g_{a\gamma\gamma}\dot{a}\mathbf{B}$$



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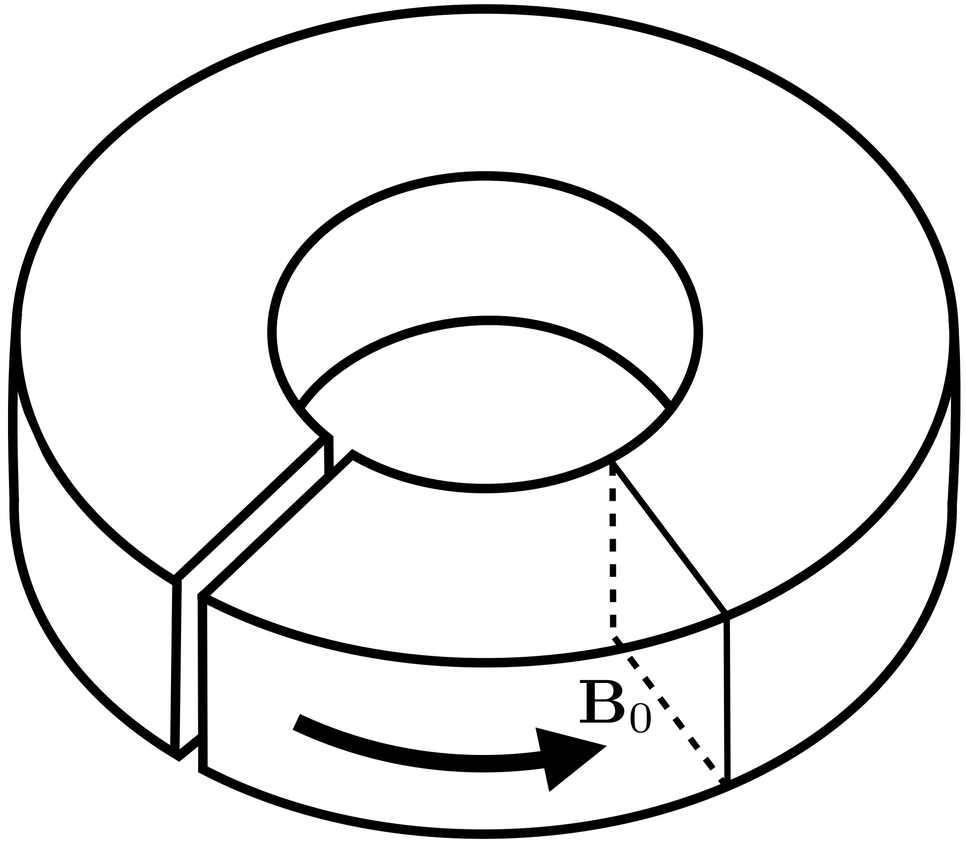

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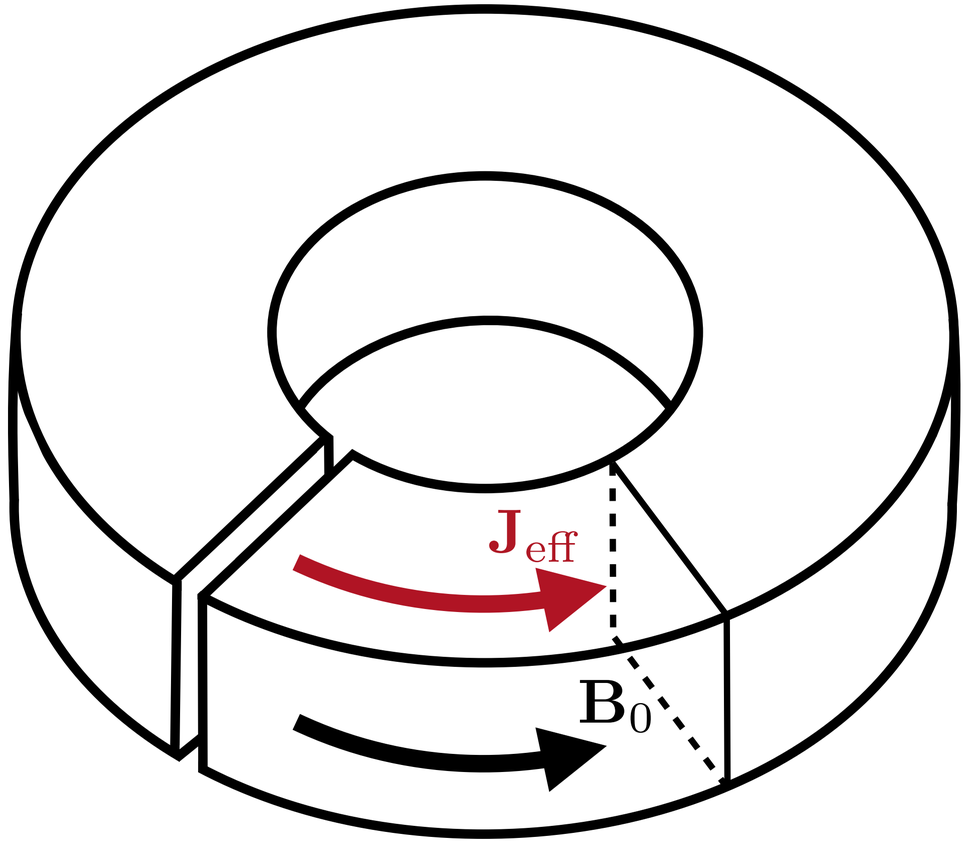

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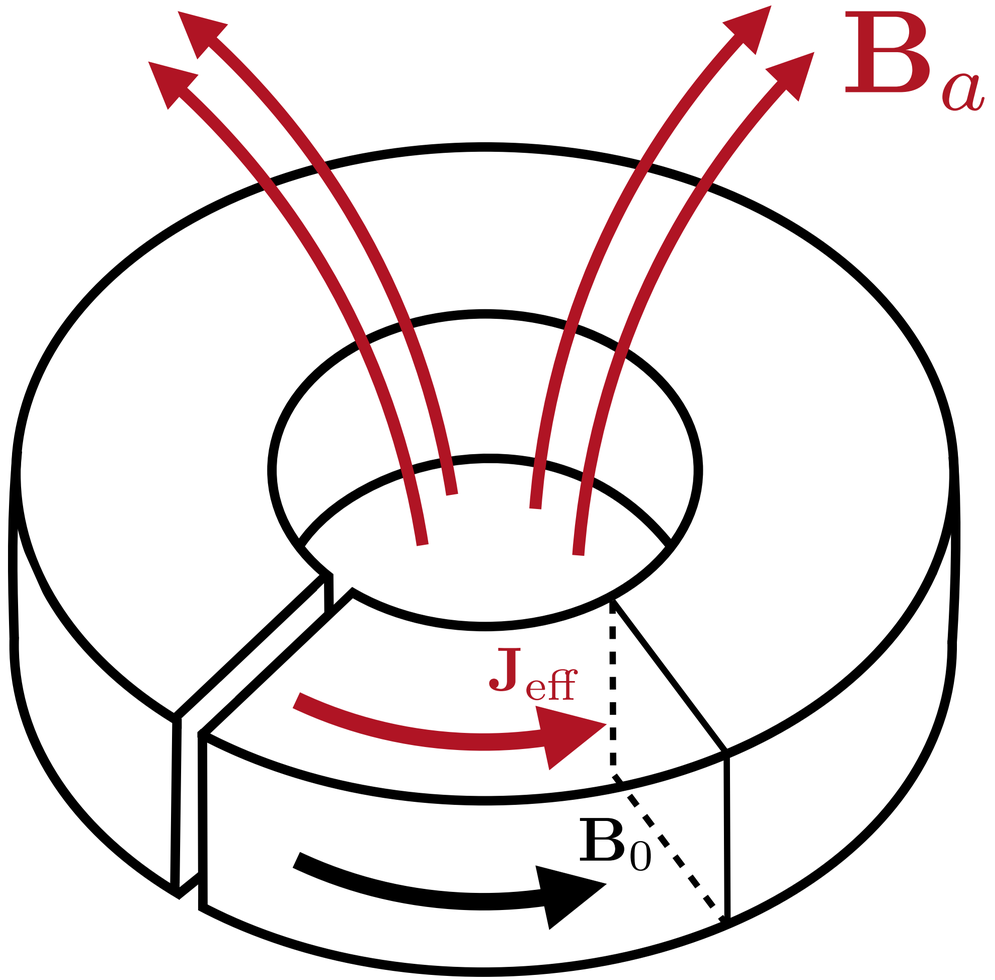

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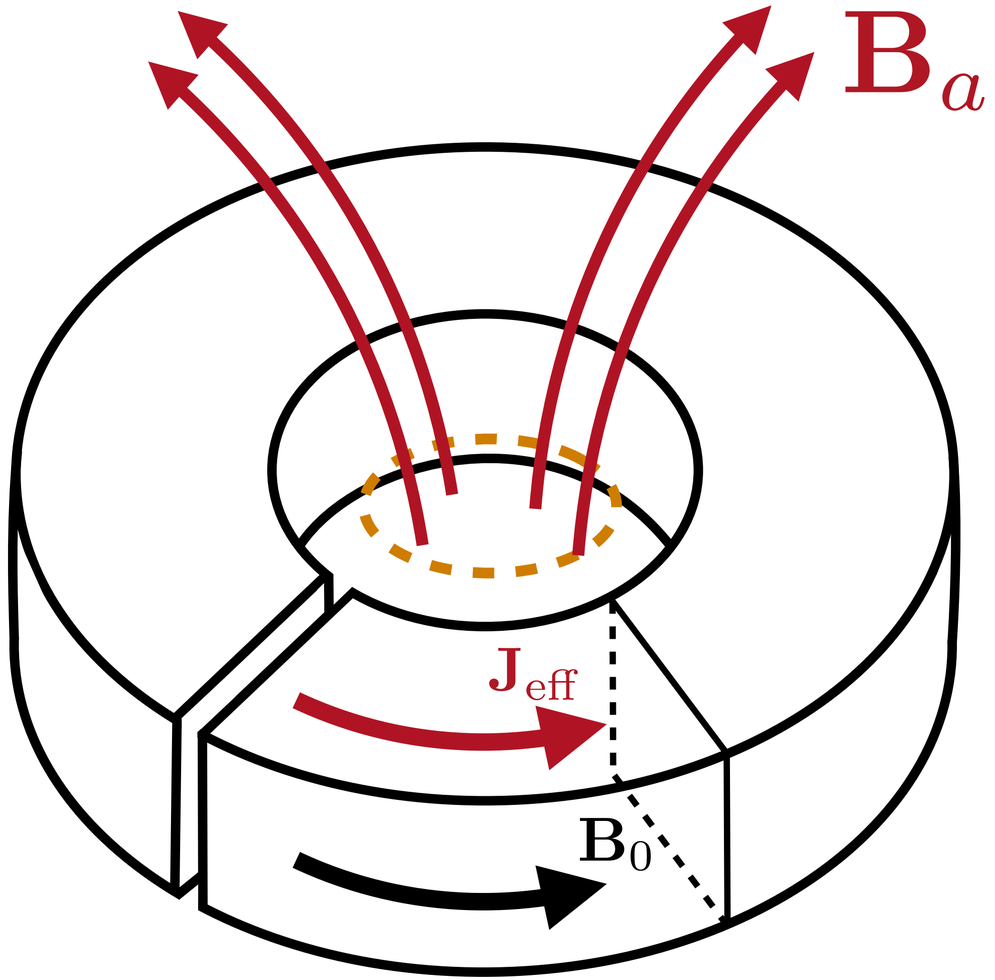

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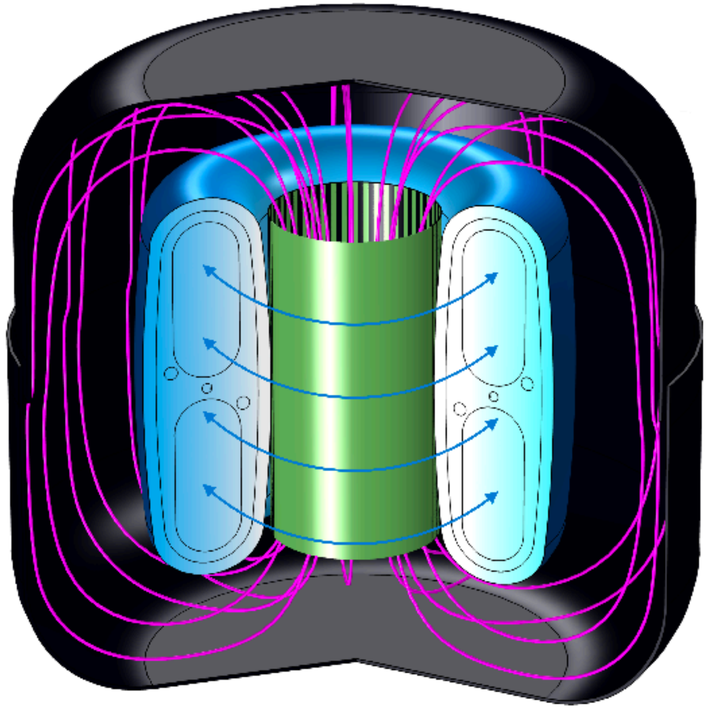

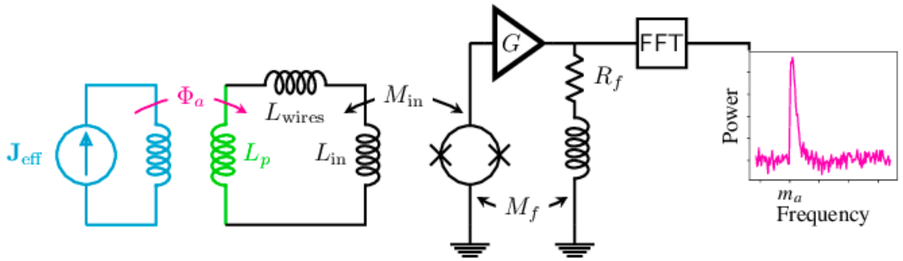

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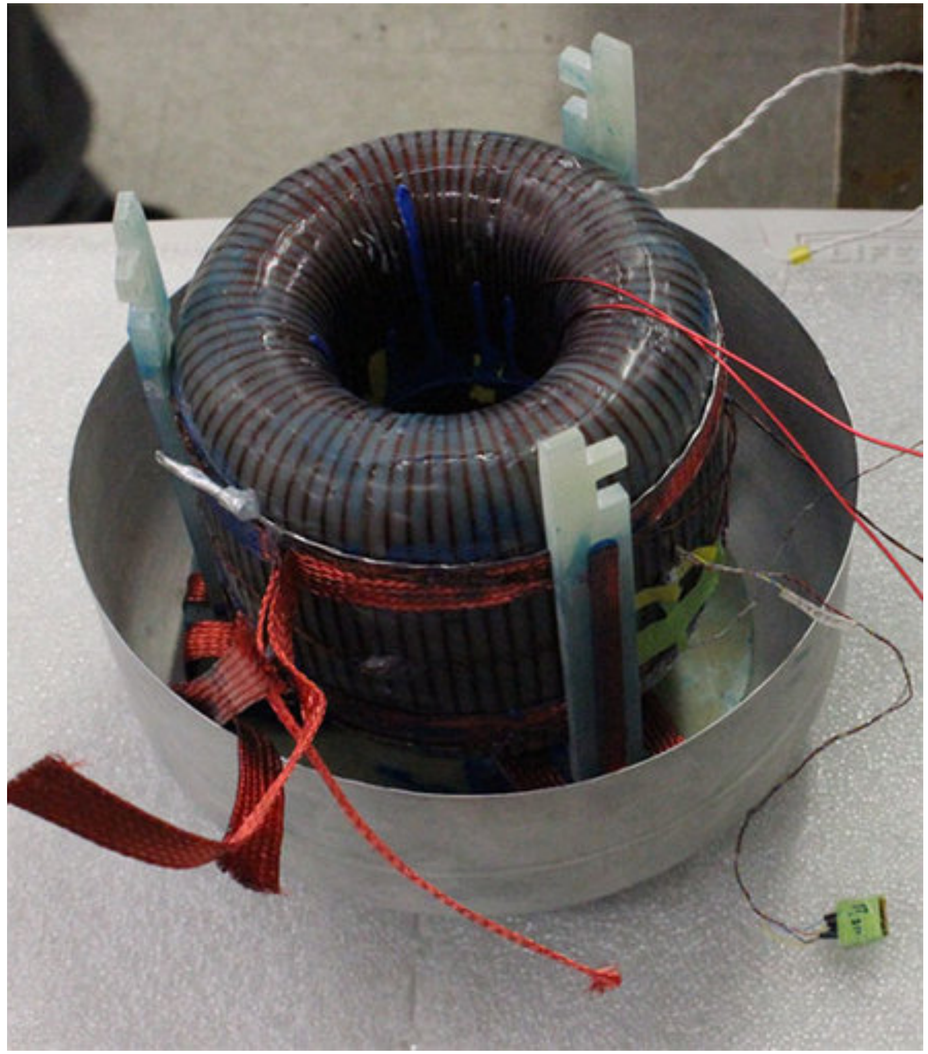
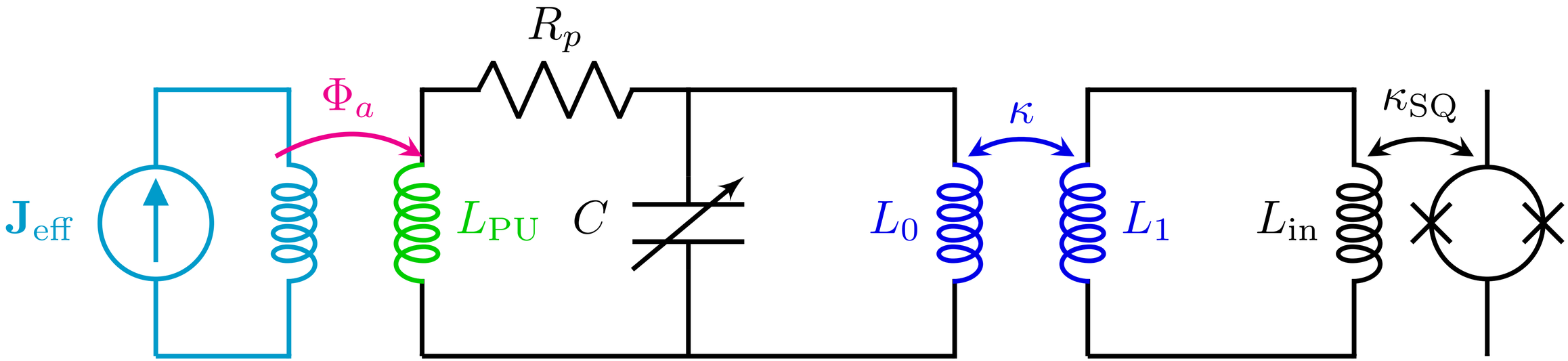


LUMPED ELEMENT EQUIVALENT CIRCUIT AND READOUT CONCEPT



$$I_{\mathrm{sig}}(\omega) = \frac{V_{\mathrm{source}}(\omega)}{Z_{\mathrm{tot}}(\omega)} \propto g_{a\gamma\gamma}, \qquad Z_{\mathrm{tot}} = Z_{R_p} + Z_C + Z_{L_0} + Z_{L_{\mathrm{PU}}}$$

Chaudhuri et al. arXiv:1803.01627 [hep-ex]

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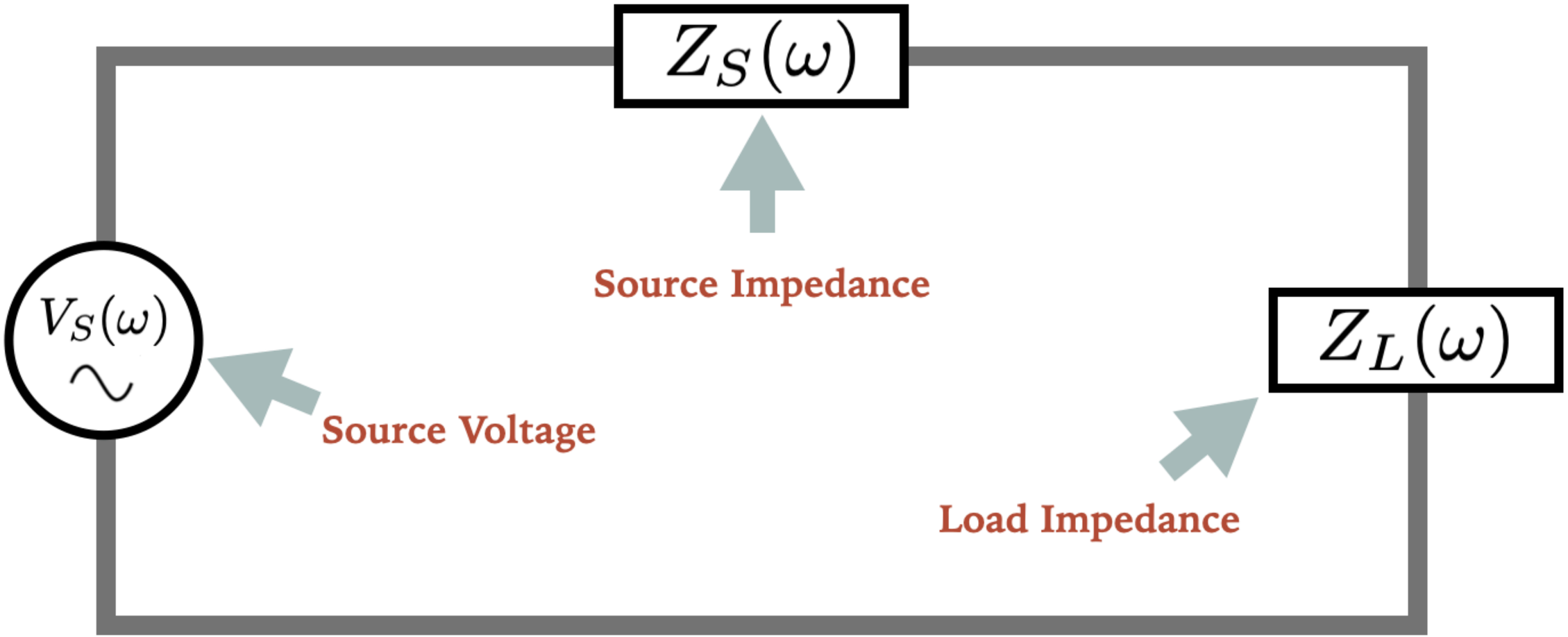
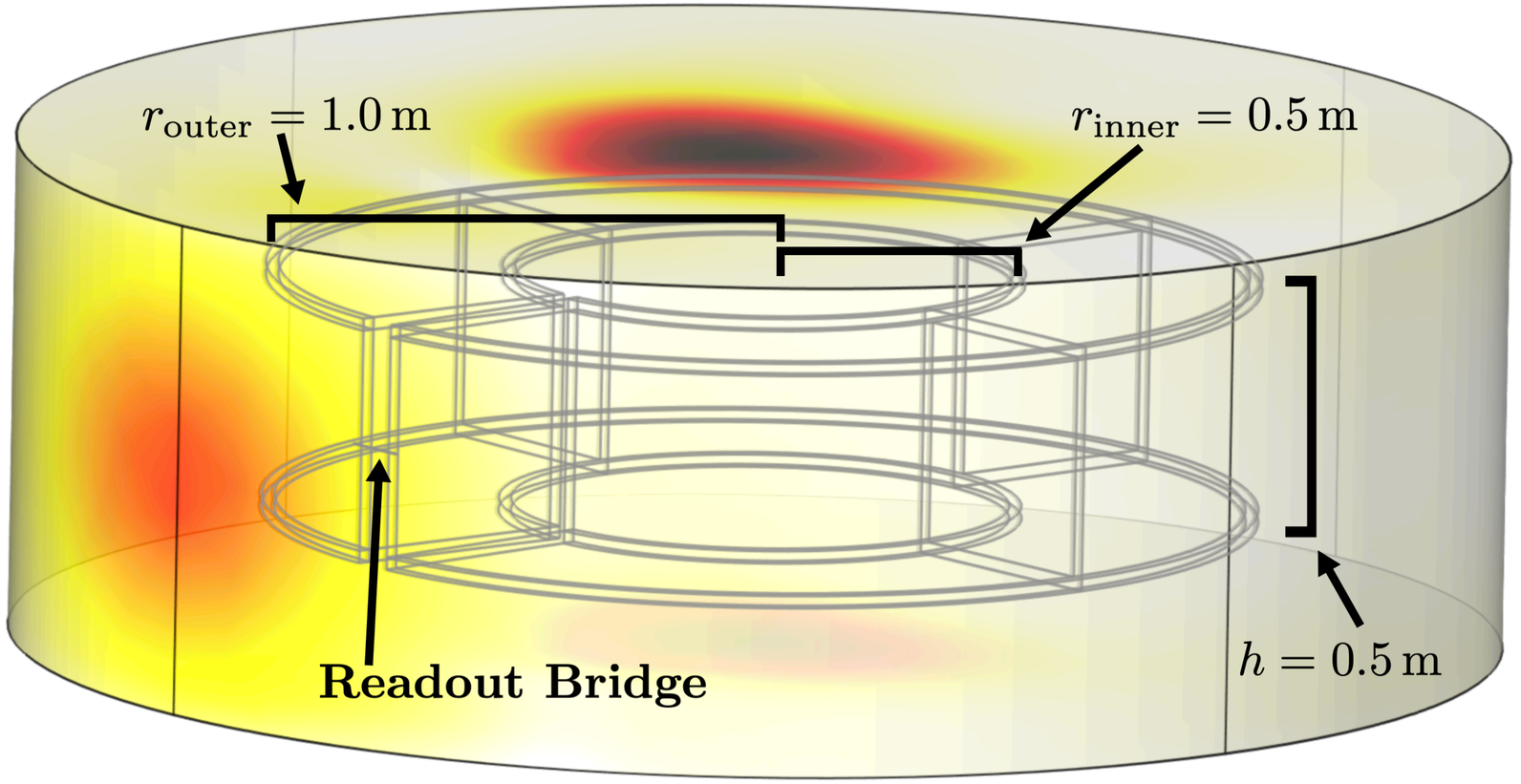
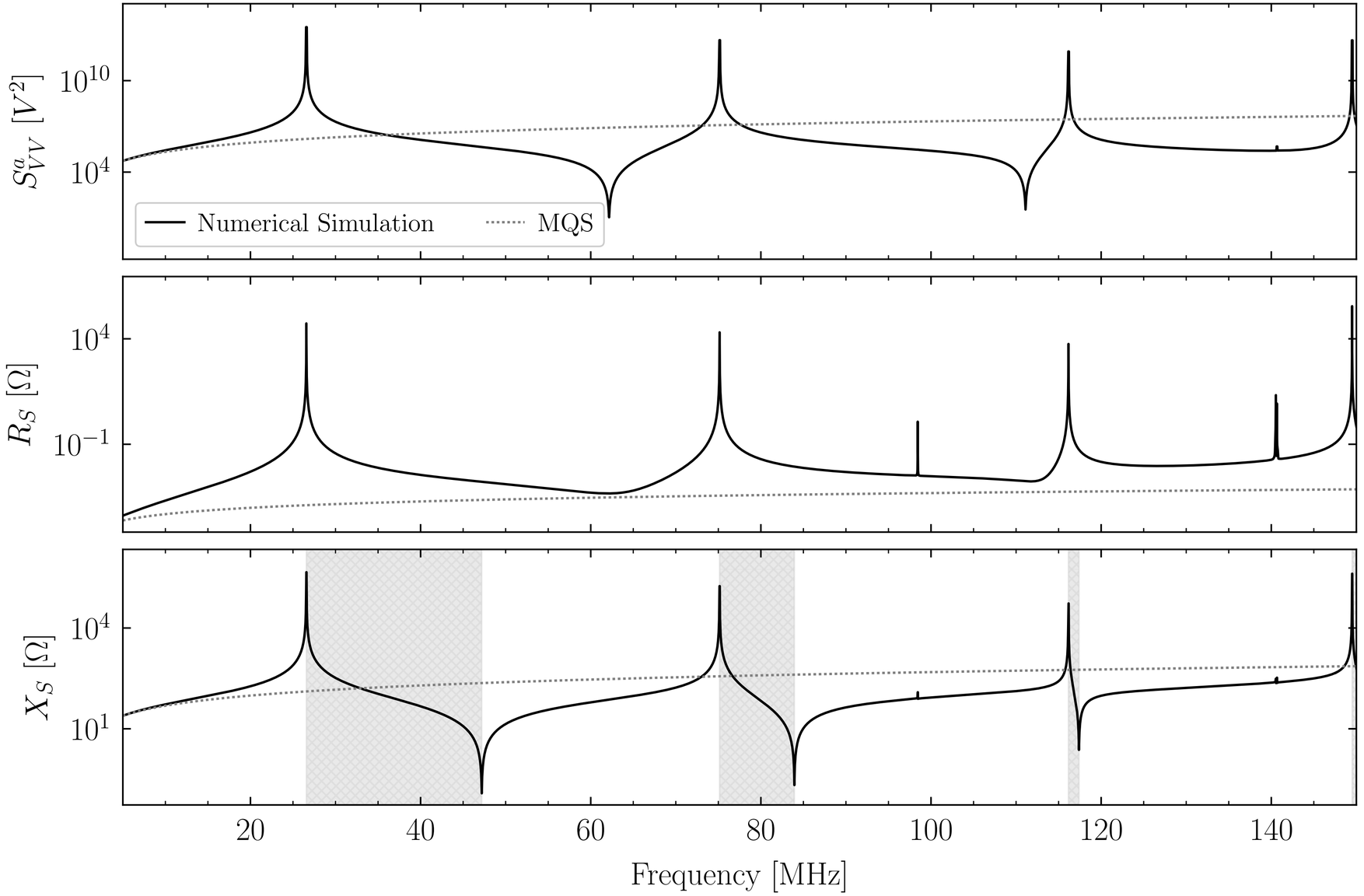
SIMPLIFIED EQUIVALENT CIRCUIT FOR LUMPED ELEMENT DETECTION



NUMERICAL SIMULATIONS OF LUMPED ELEMENT DETECTORS WITH COMSOL



NUMERICAL SIMULATION FOR DETECTOR CHARACTERIZATION



LUMPED ELEMENT EQUIVALENT CIRCUIT AND READOUT CONCEPT

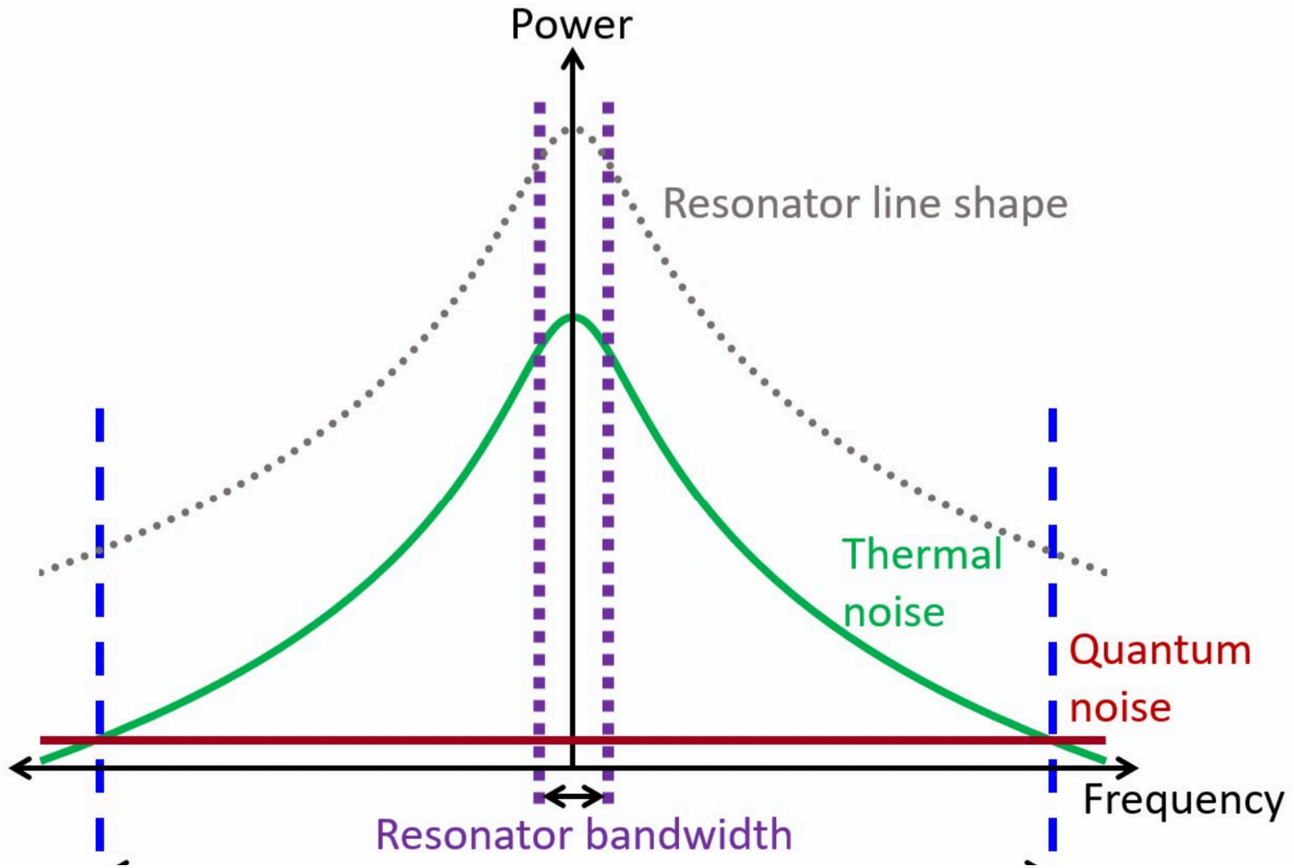
$$I^2_{\mathrm{sig}}(\omega) = \frac{V_S(\omega)^2}{R^2 + X_{\mathrm{tot}}(\omega)^2}$$

Quasistatic Approximation

$$X_L(\omega) = \omega L$$

$$X_C(\omega) = -\frac{1}{\omega C}$$

$$I_{\mathrm{sig}}(\omega) \approx \frac{V_S(\omega)^2}{R^2}\left[1 - \frac{L^2}{R^2}(\omega - \omega_r)^2\right]$$



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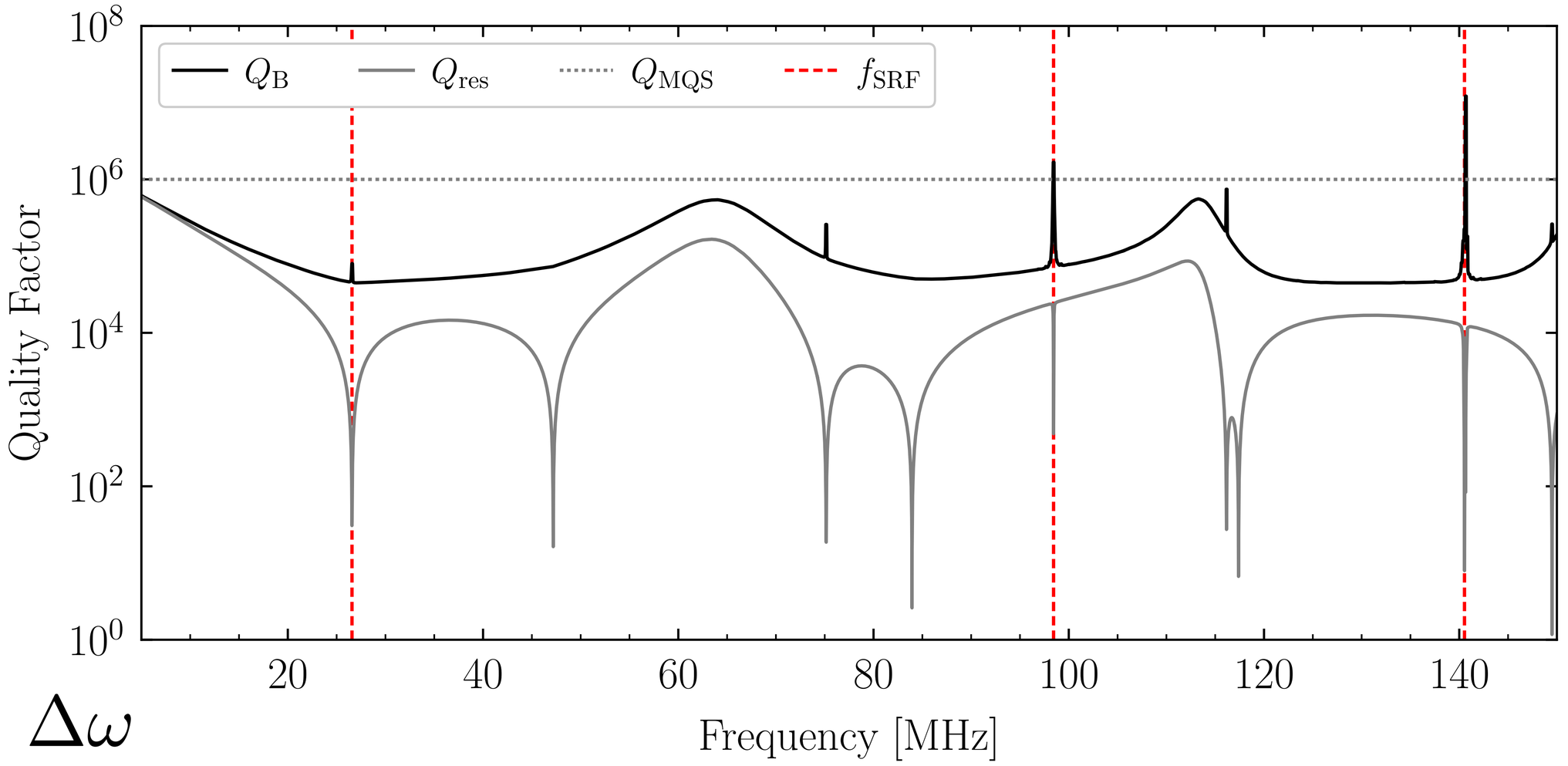
SCANNING SENSITIVITIES FOR LUMPED ELEMENT DETECTION



$$Q \approx \frac{\Delta\omega}{\omega_{res}}$$

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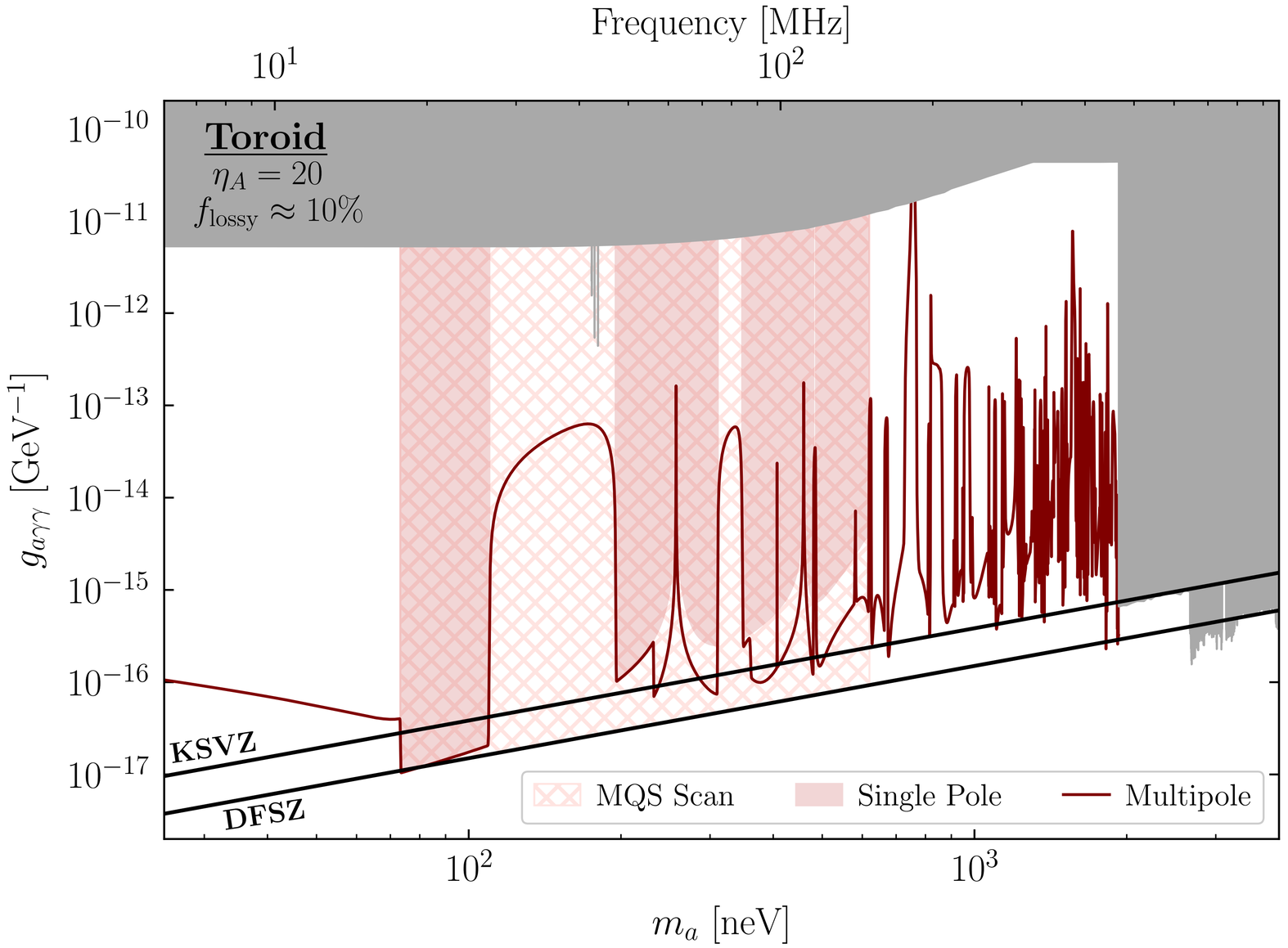
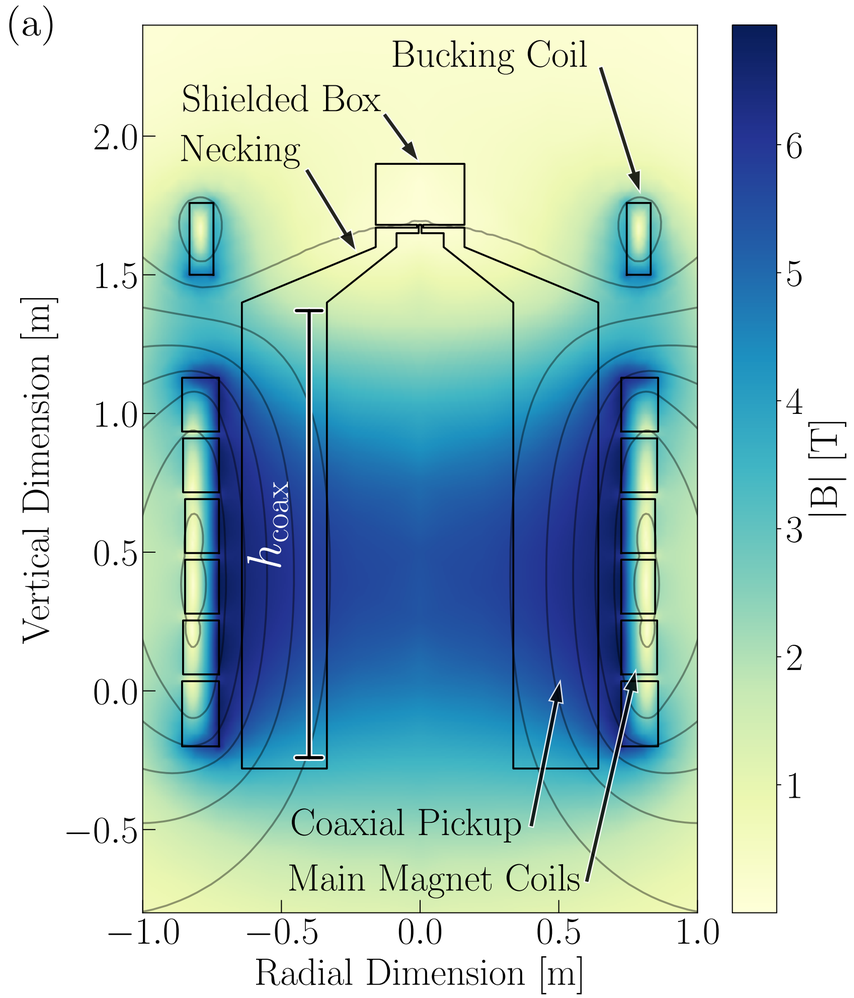
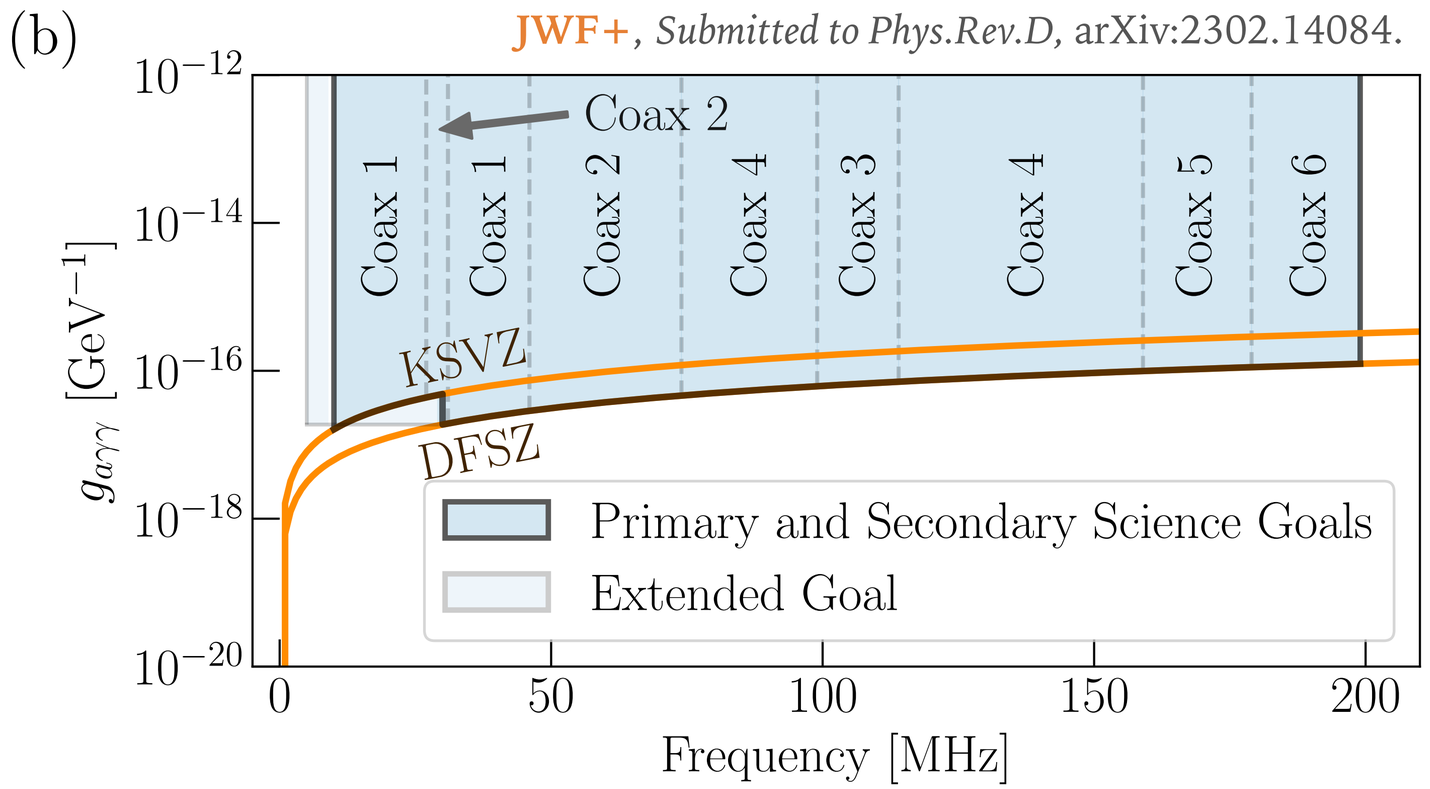
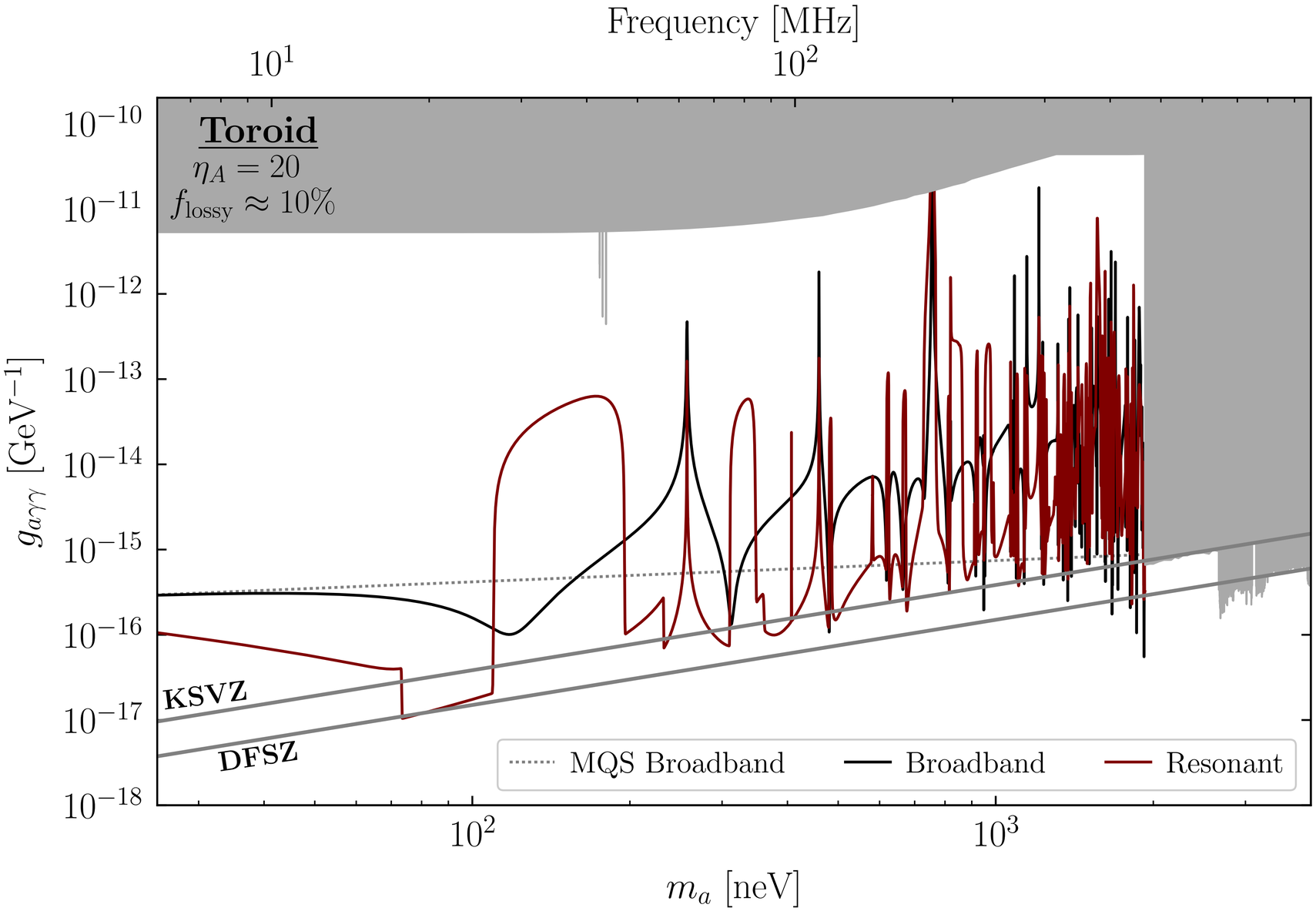


THE FUTURE OF LUMPED ELEMENT DETECTION





BROADBAND SENSITIVITIES FOR LUMPED ELEMENT DETECTION



BACKUP SLIDES

QUANTUM LIMITED SENSITIVITIES FOR LUMPED ELEMENT DETECTORS

Total Noise PSD

Thermal noise

Noise-generating resistance

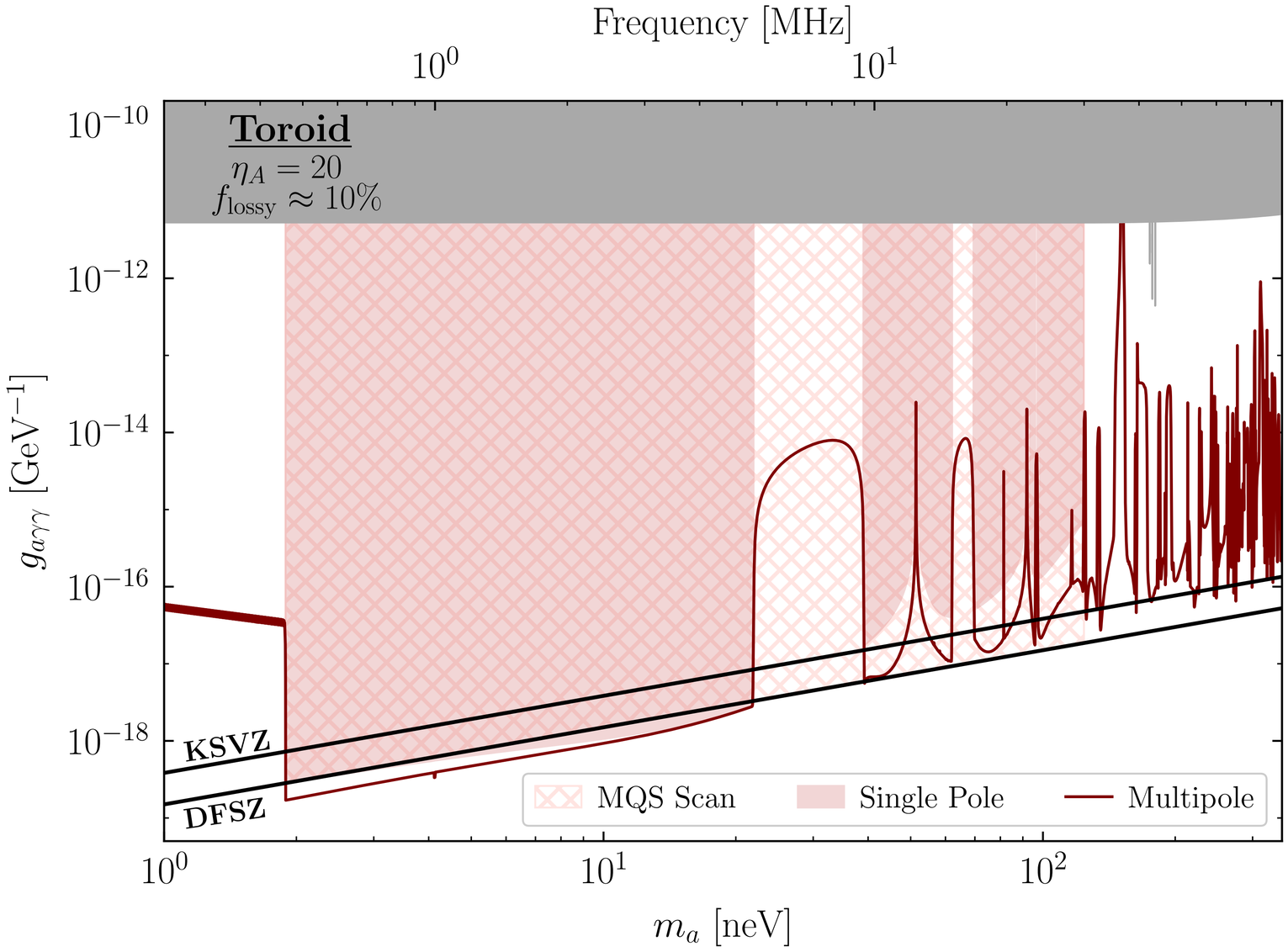
Imprecision Noise

$$S_{II}^{\mathrm{noise}}(\omega) = \frac{2\omega}{\pi}\left[\frac{1}{\exp(\omega/T)-1}+\frac{1}{2}\right]\frac{R_{\mathrm{th}}}{|Z(\omega)|^2}+\frac{S_{II}^{\mathrm{imp}}}{2\pi}+\frac{S_{VV}^{\mathrm{BA}}}{2\pi|Z(\omega)|^2}$$

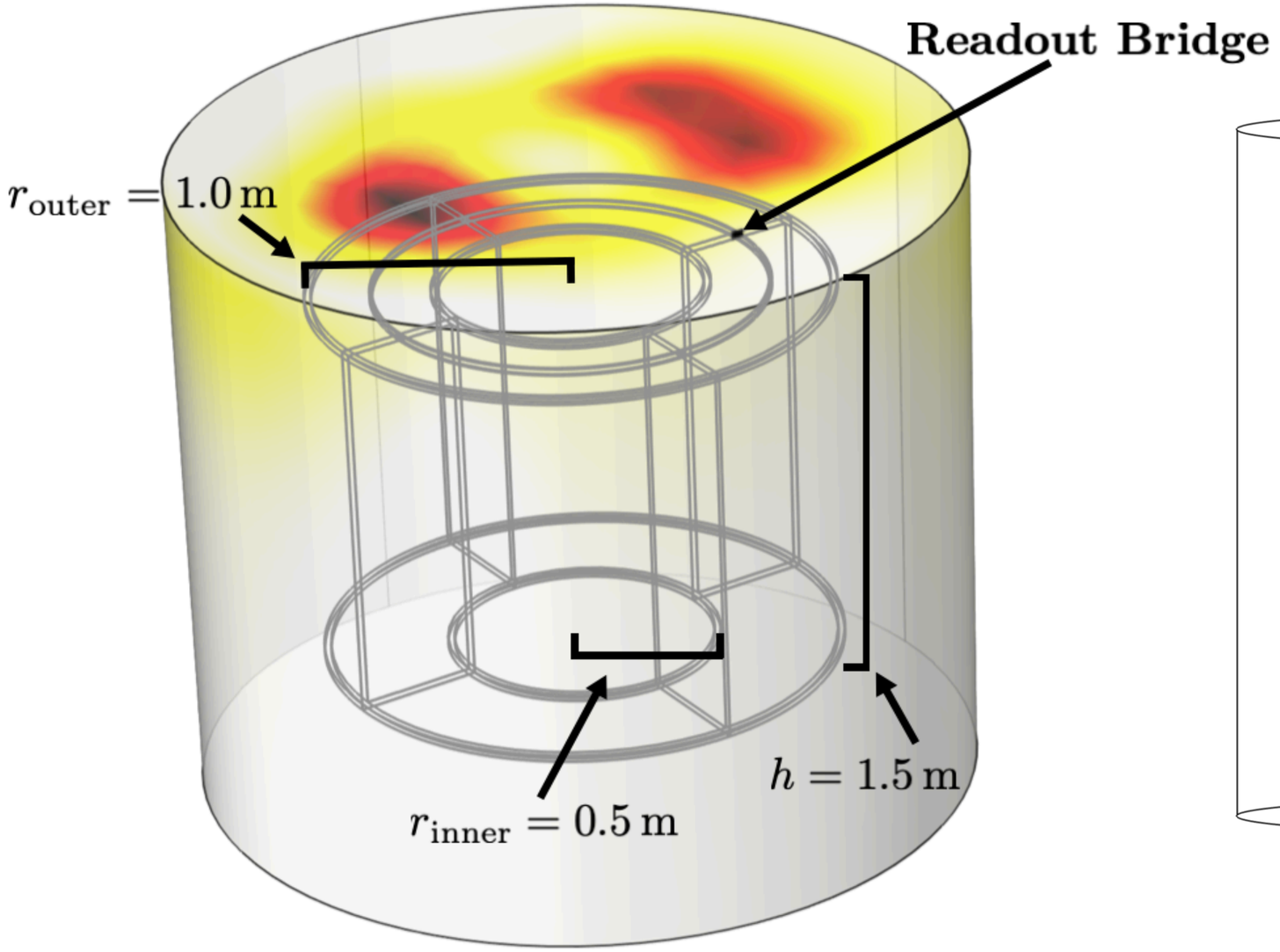
Backaction Noise

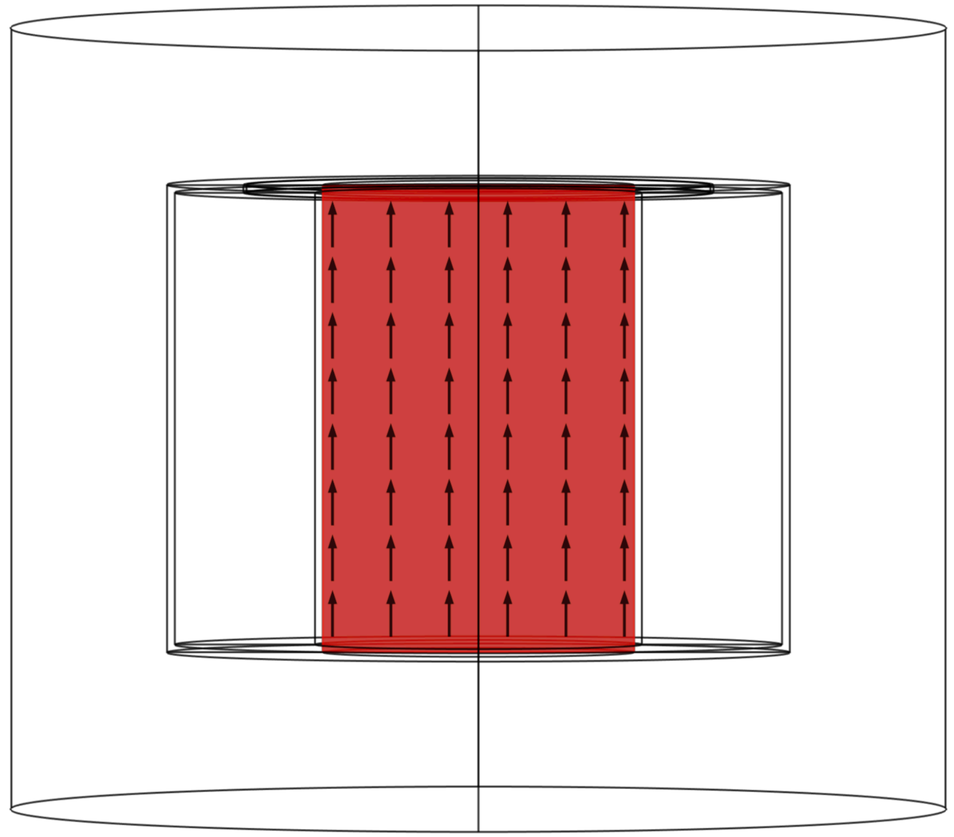
$$\eta_A = \frac{\sqrt{S_{II}^{\mathrm{imp}} S_{II}^{\mathrm{BA}}}}{\omega}$$

DMRADIO-GUT SENSITIVITY PROJECTIONS



SENSITIVITY WITH A SOLENOIDAL GEOMETRY





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