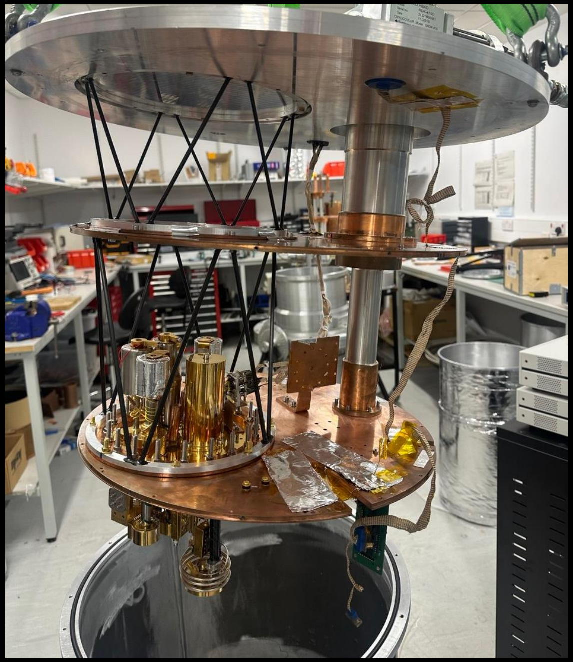
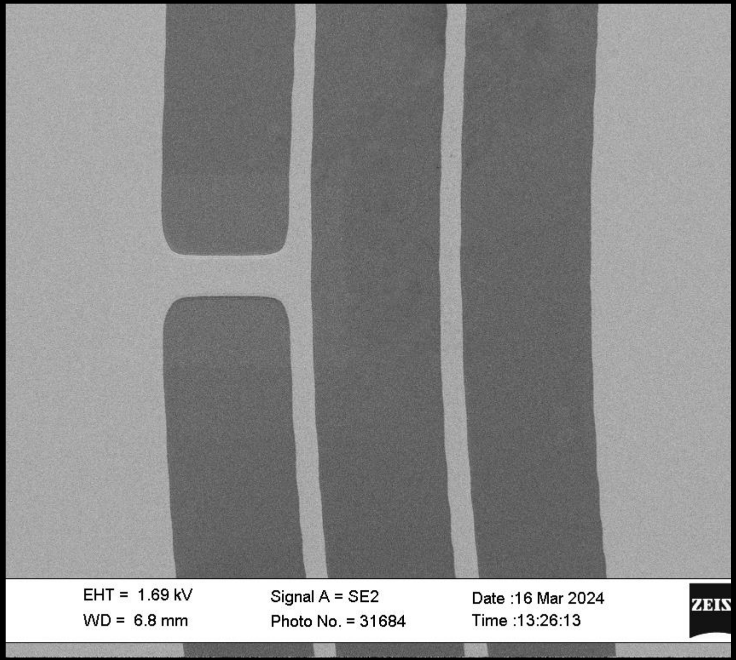
High-Frequency Axion Dark Matter Searches at Manchester

Jamie McDonald | University of Manchester





Annual APP and HEPP Conference| Edinburgh 8 - 10 April 2026

On behalf of
Ades, Battye, Buck, Feasby, Gilles, Gramellini, Marchitelli, **JM**, McCulloch, Lancaster, Mohammadian, Piccirillo, Preston, Qureshi, Rukhadze, Smith, Upward, Wystemp

Axion Experiments at the University of Manchester


Ted Smith


Lucio Piccirillo


Babak Mohammadian


Matt Millns

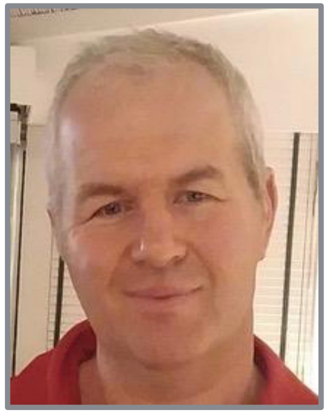

JM


Mark McCulloch


Mark Lancaster


Elena Gramellini

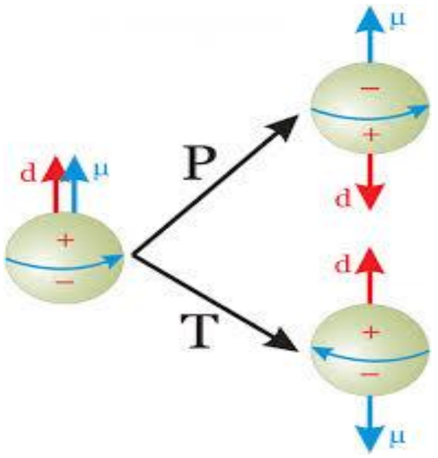

Valerio Gilles


Richard Battye

Technical Staff: Daren Shepherd, Joshua Major, Noel Minzie,

MPhys & MSc Students: Nodar Rukhadze, Oliver Ades

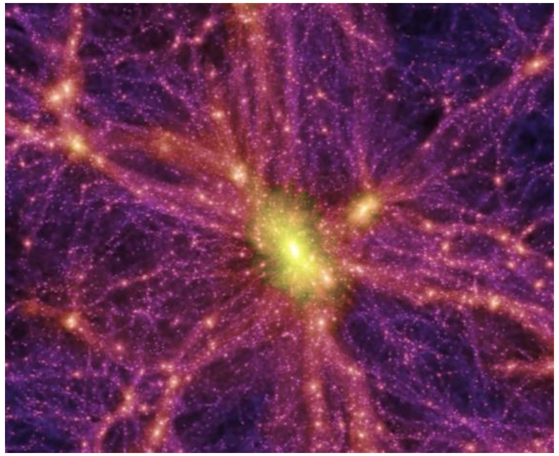
Axions



Solve strong CP problem in QCD

(why neutron EDM so small?)

Peccei & Quinn (1977)



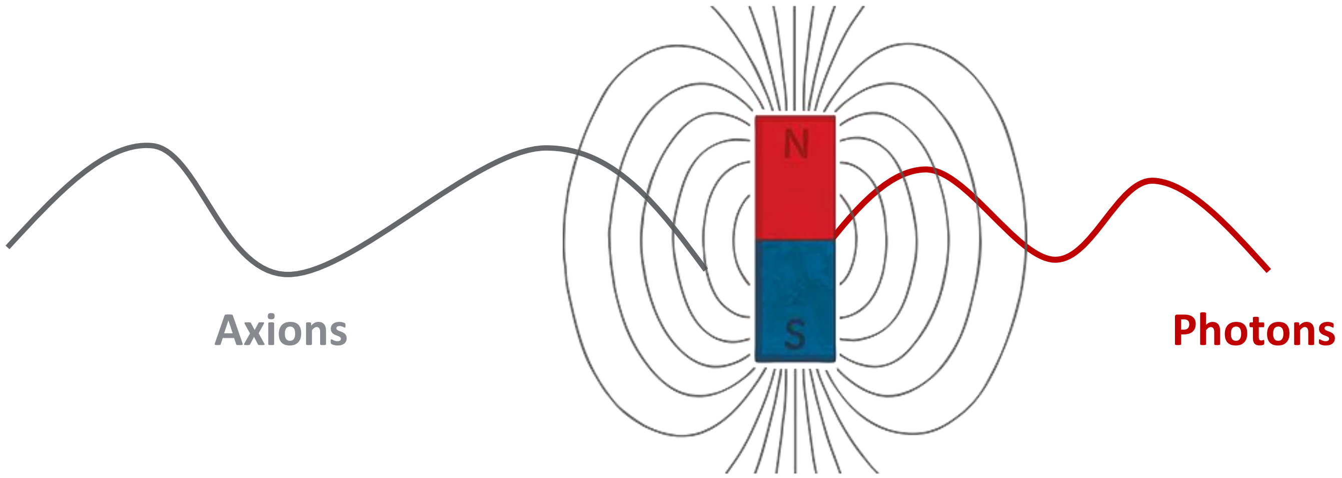
Natural dark matter candidates

($m_{DM} \sim 10^{-6}\mathrm{eV}$ << GeV)

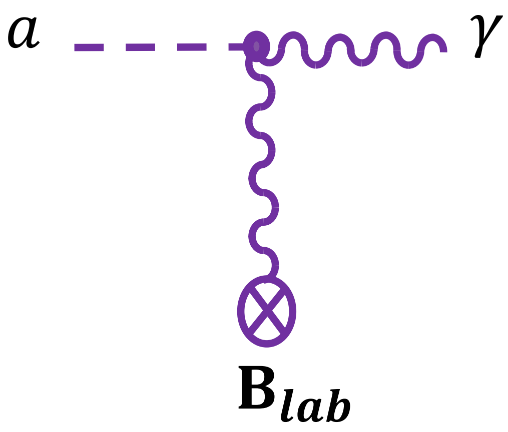
Dine & Fischler (1983), Abbott & Sikivie (1983), Preskill, Wise & Wilczek (1983).

Axions

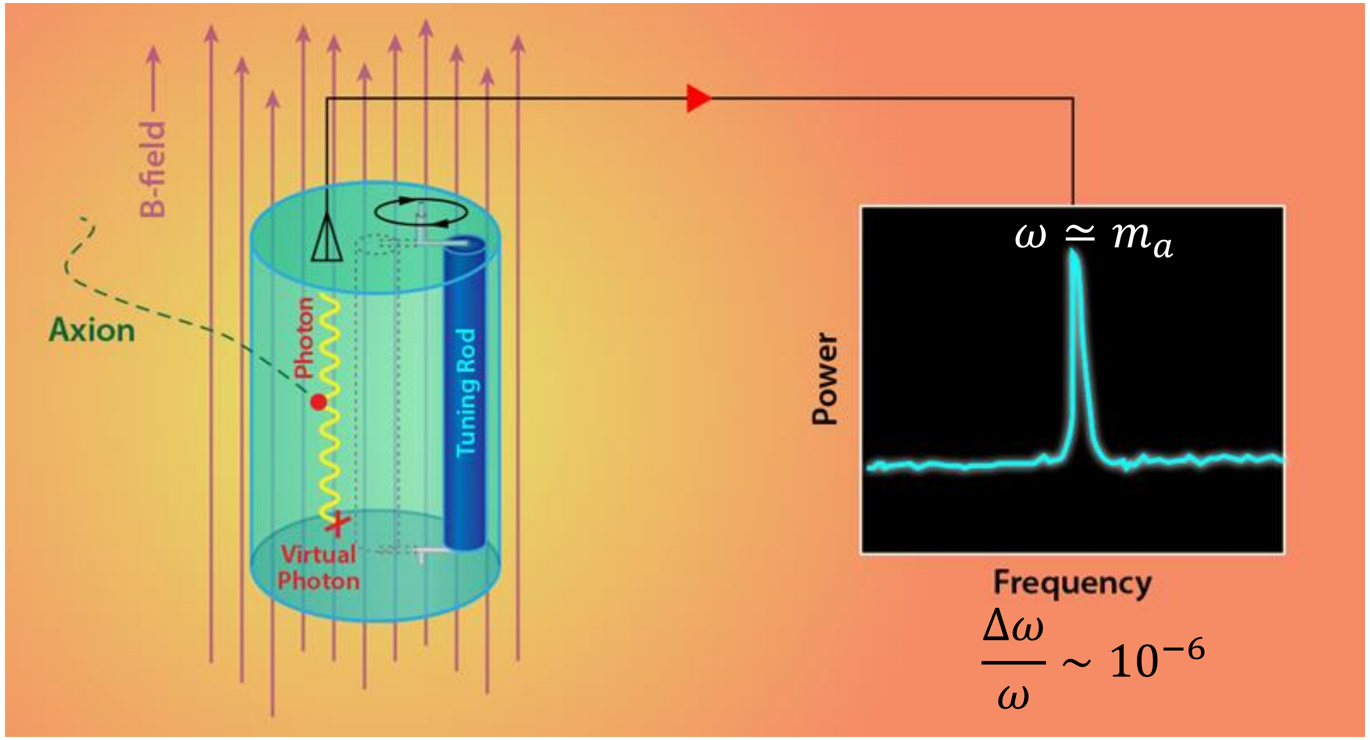
$$\mathcal{L} = -\frac{g_{a\gamma\gamma}}{4} \mathrm{a}\, \mathrm{F}_{\mu\nu} \tilde{F}^{\mu\nu} = g_{a\gamma\gamma} a\, \boldsymbol{E}.\boldsymbol{B}$$



Axion Dark Matter



$$a \propto e^{i\omega t} \qquad \omega \simeq m_a + \frac{1}{2} m_a v_{DM}^2$$

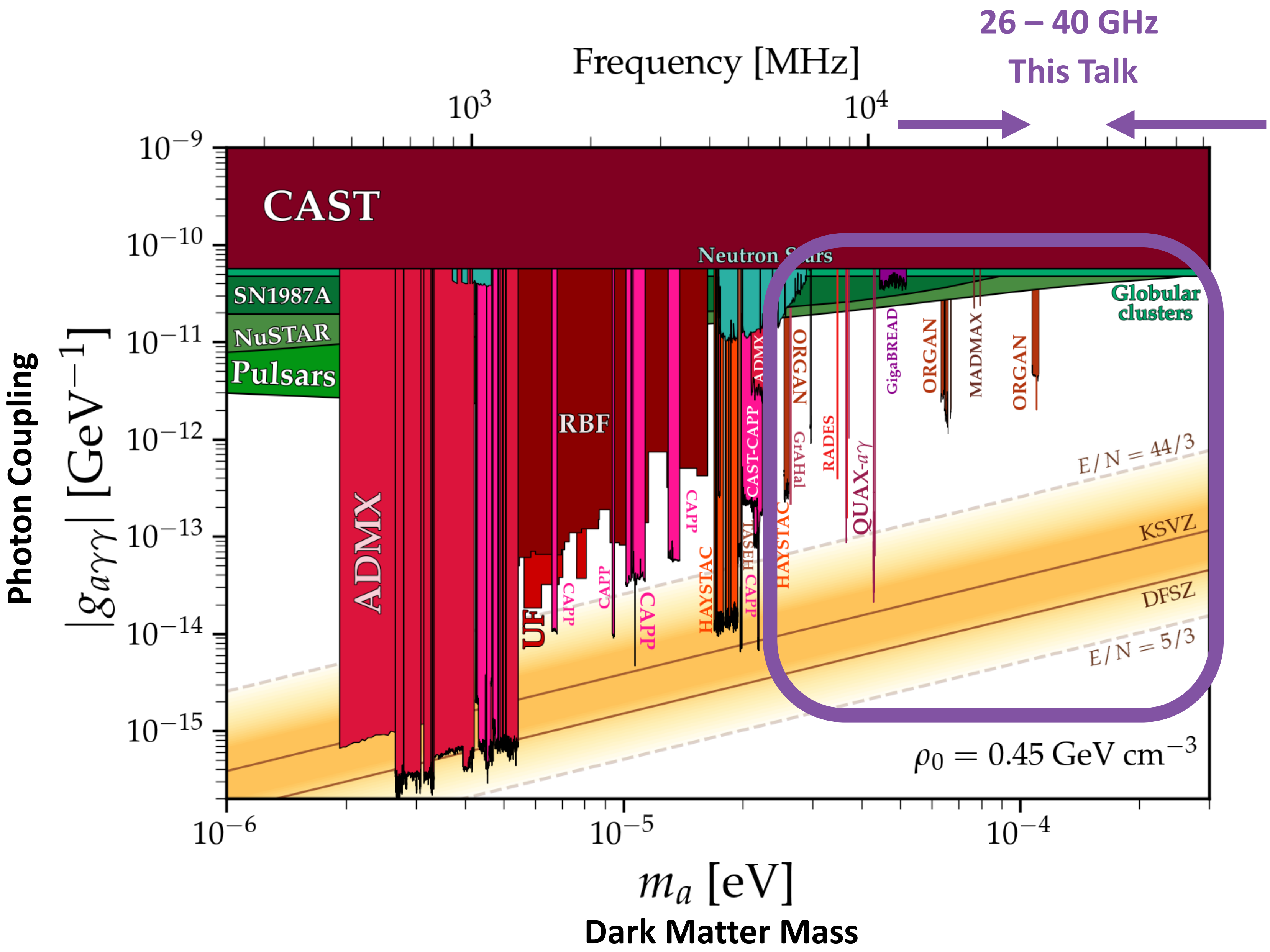


$$\omega \simeq m_a$$

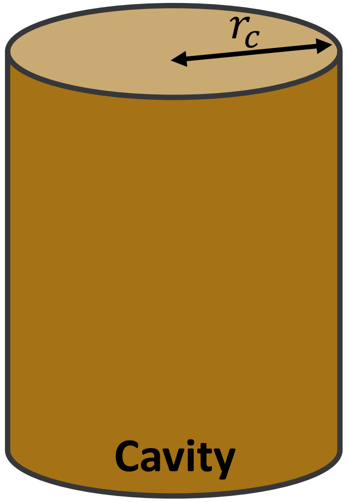
$$\frac{\Delta\omega}{\omega} \sim 10^{-6}$$

Axion Dark Matter

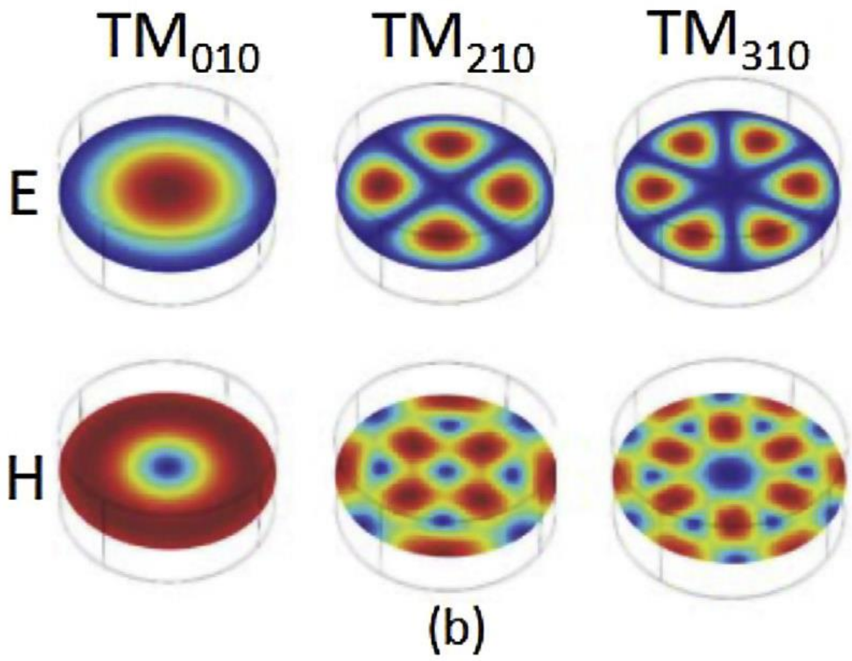
$$\mathcal{L} = -\frac{g_{a\gamma\gamma}}{4} a\, F_{\mu\nu} \tilde{F}^{\mu\nu}$$



Cavity Searches for Axion Dark Matter



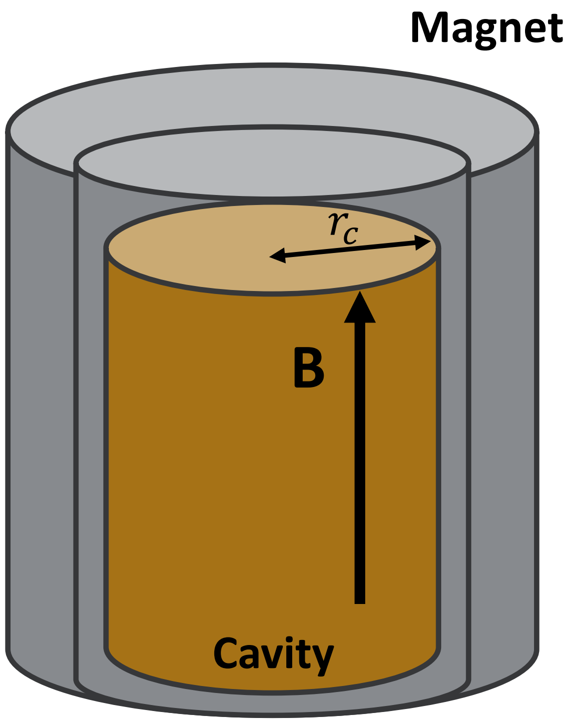
Cavity Modes

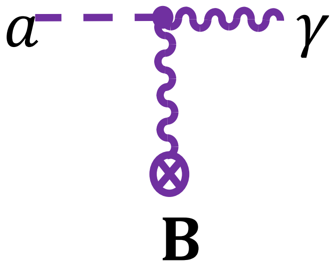


$$f_{lmn}$$

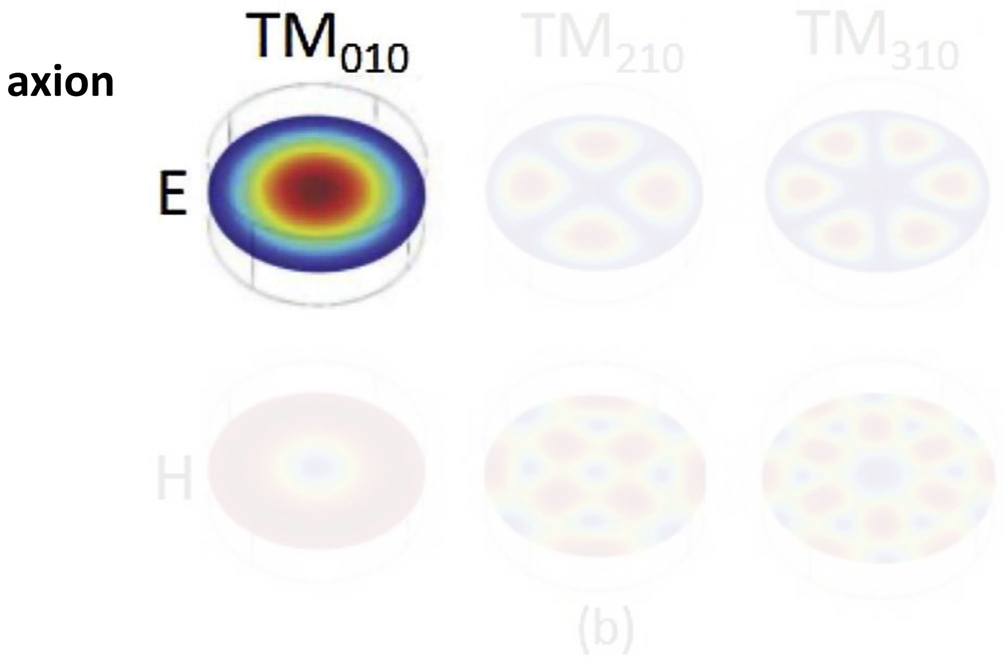
(eigenfrequencies)

Cavity Searches for Axion Dark Matter





Cavity Modes

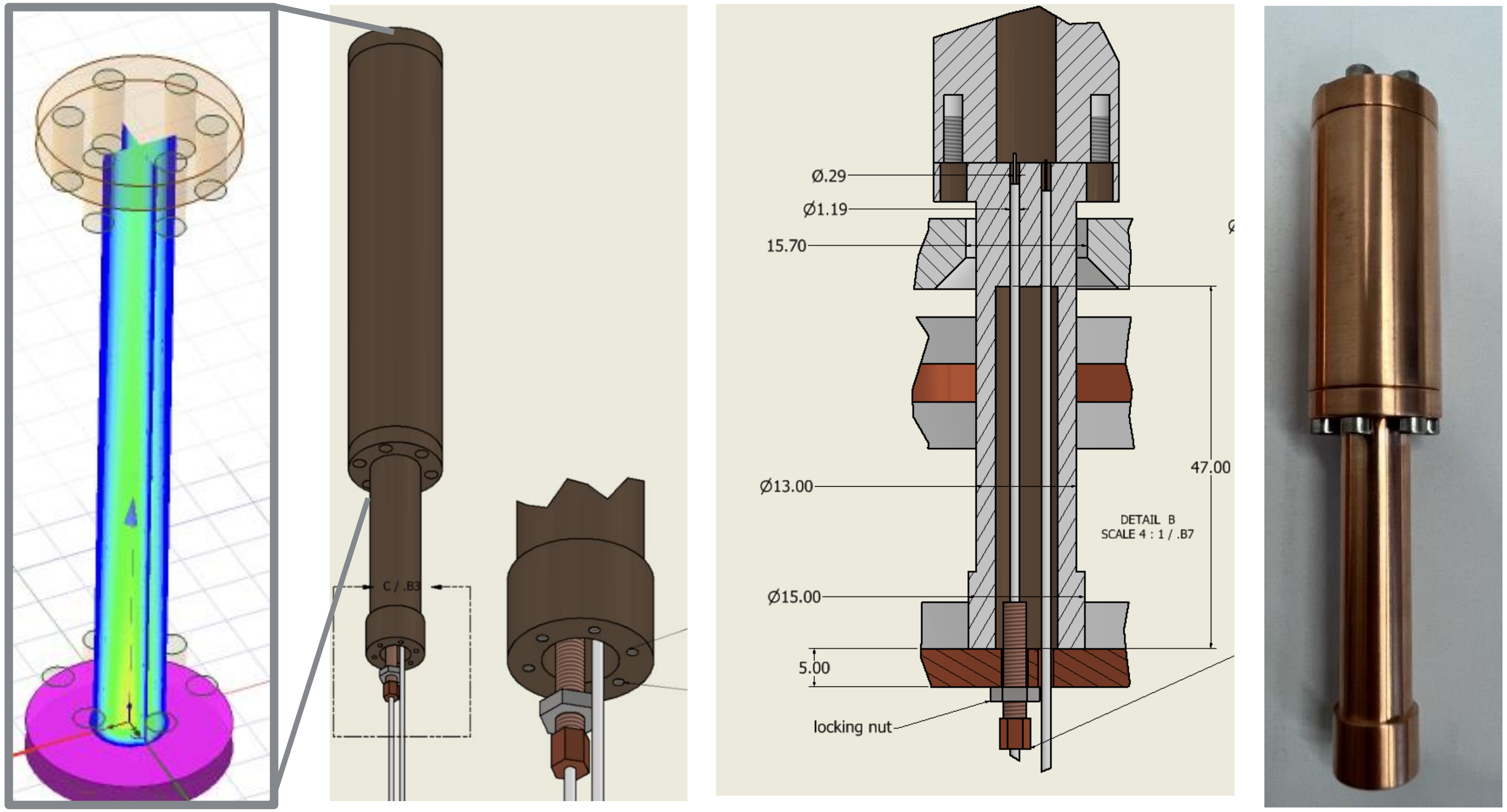


$$f_{010} \sim 1/r_c \sim f_{axion} \sim m_a$$

(eigenfrequencies)

Cavity Searches for Axion Dark Matter

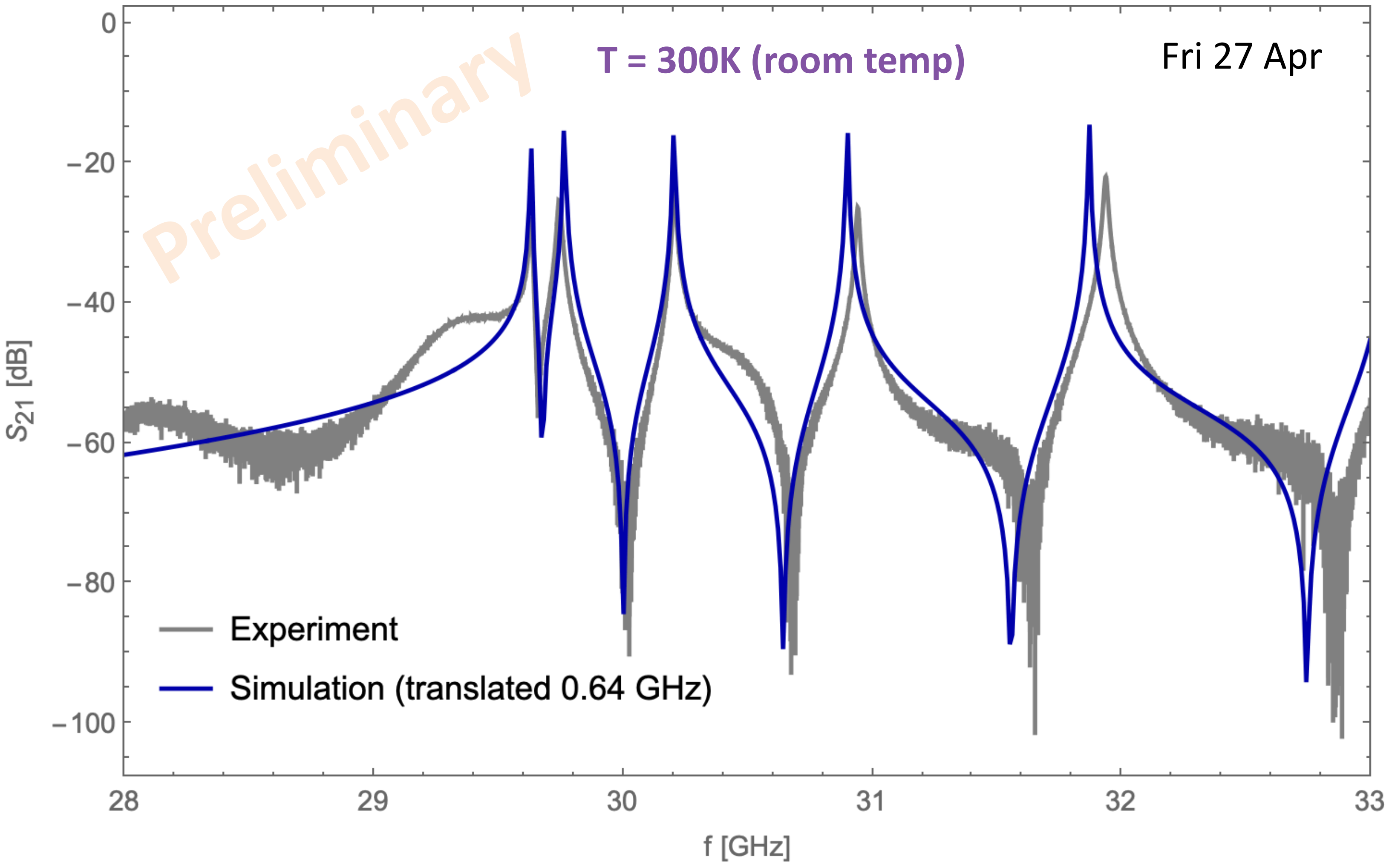
30 GHz Static Pillbox Cavity



Cavities

Magnet

Cavity Mode Structure Verification



$$S_{12}(dB) = 10 \log\left(\frac{P_{out}}{P_{in}}\right)$$

"transmission spectrum"

First Q measurement likely over-coupled: more measurements coming soon!

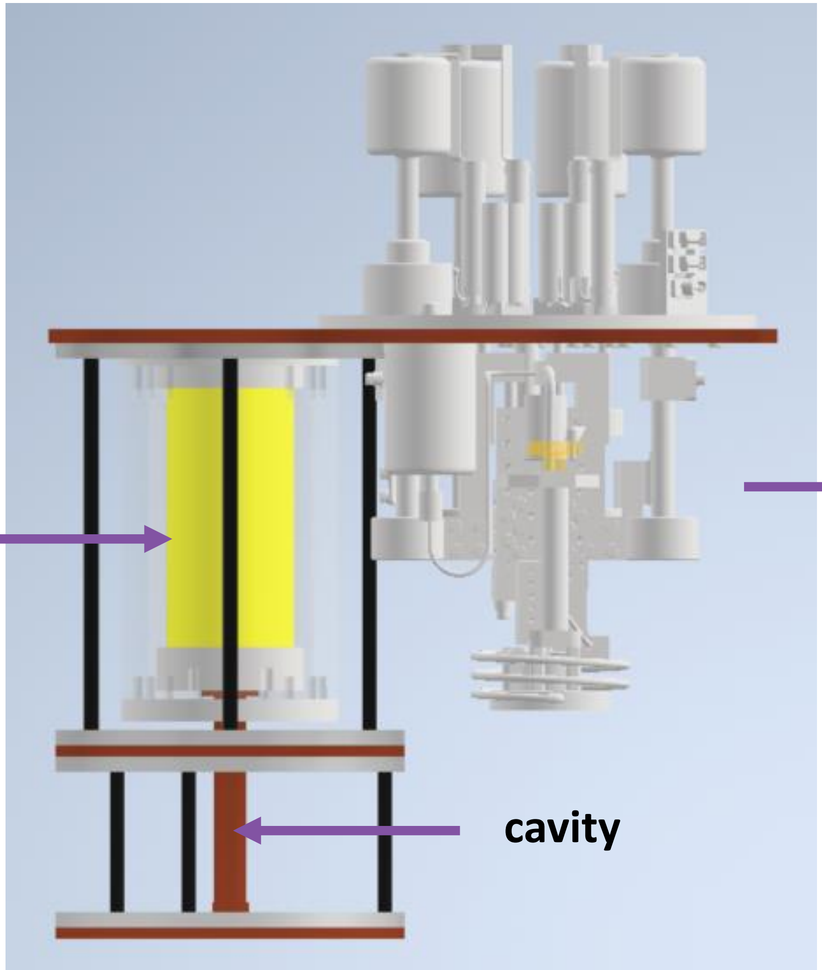
Cryostat

4 K

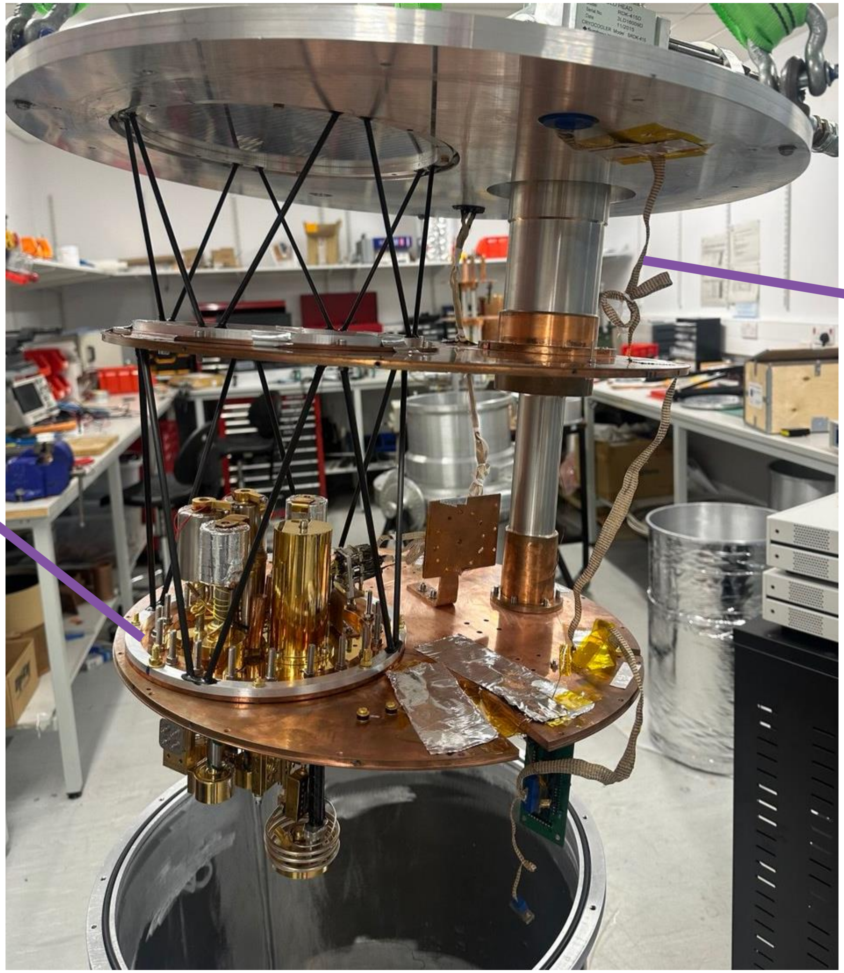
magnet

300 mK

50 mK



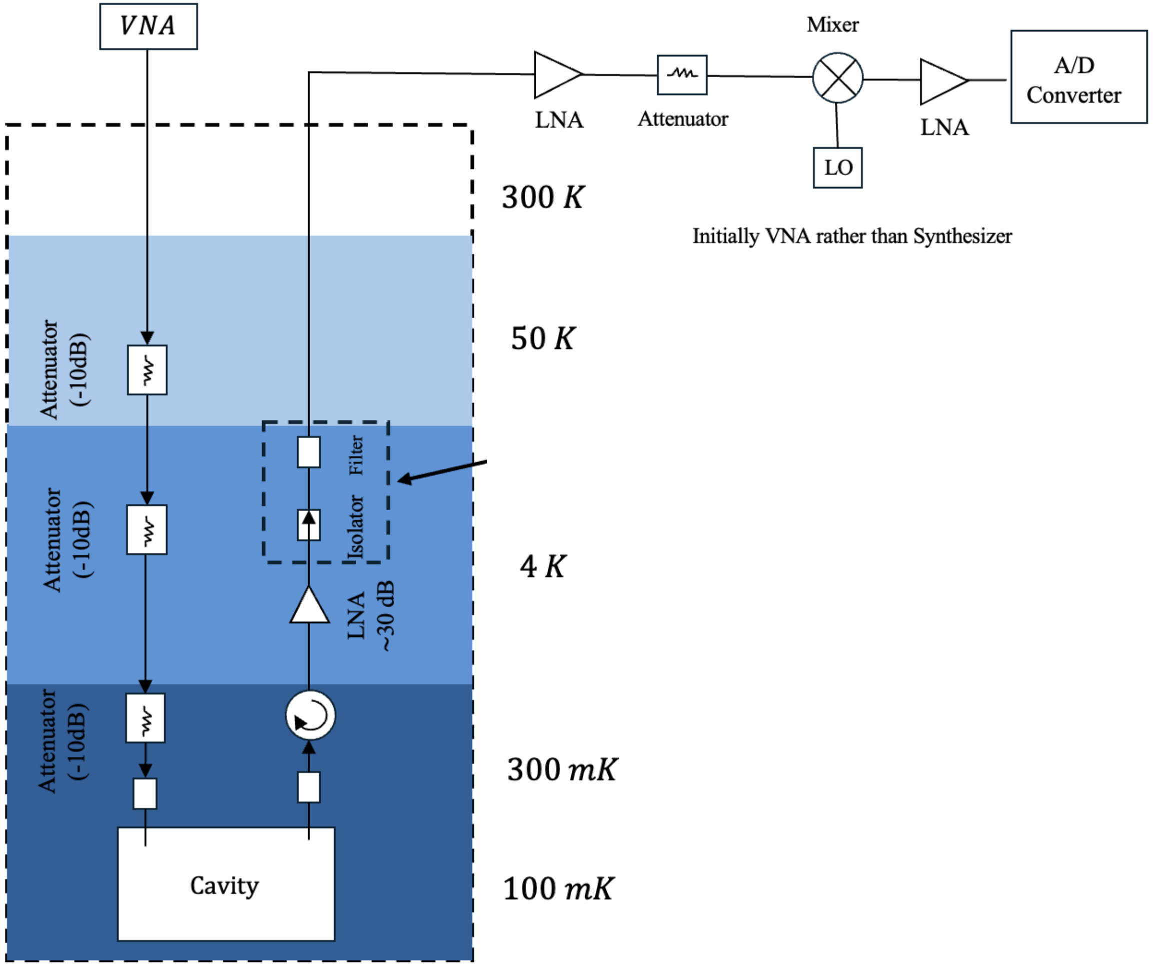
Miniature
Dilution
Fridge

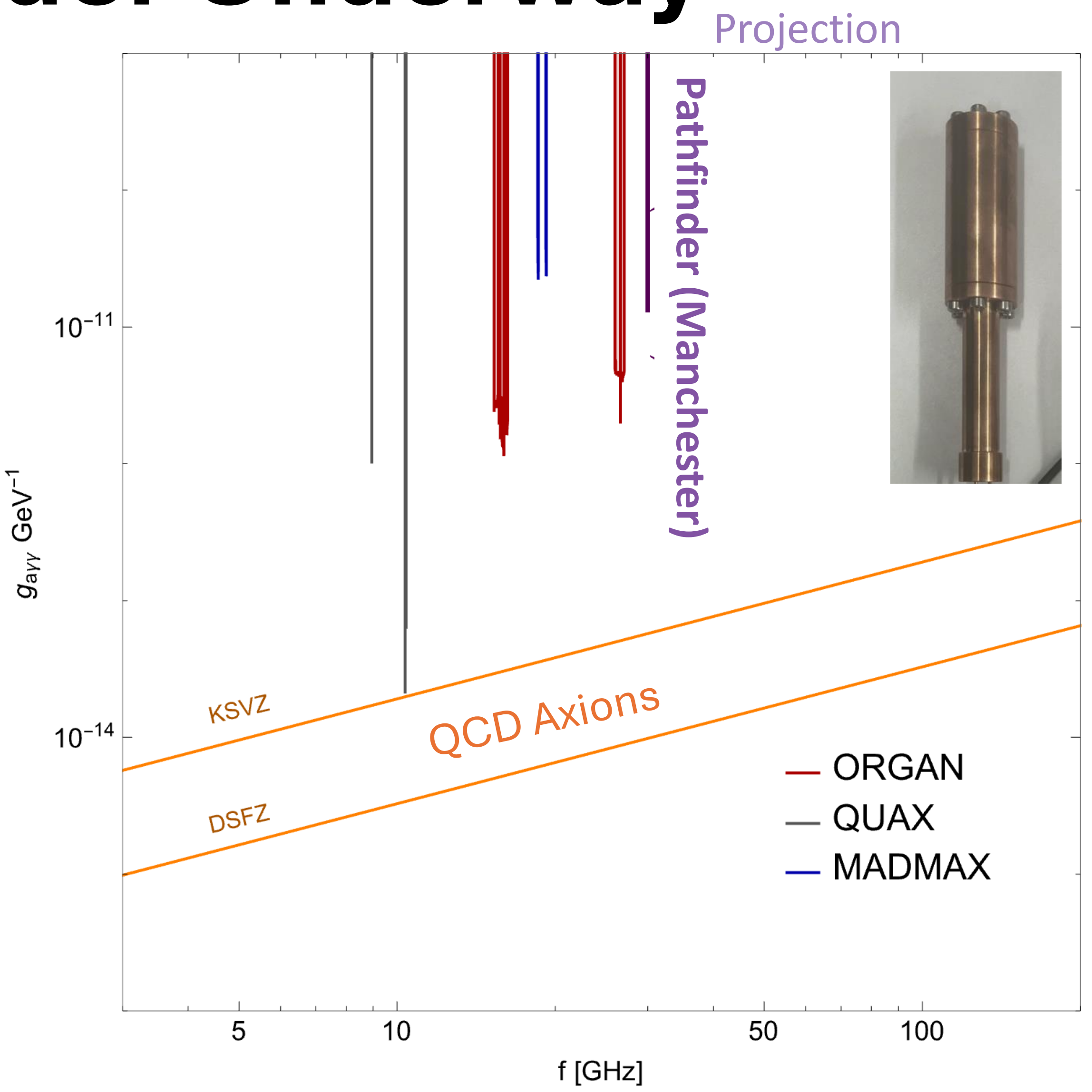


Cryo-Cooler
to 4 K

@ 30 GHz: T_{Quant} = 1.4 K

30GHz Pathfinder Underway



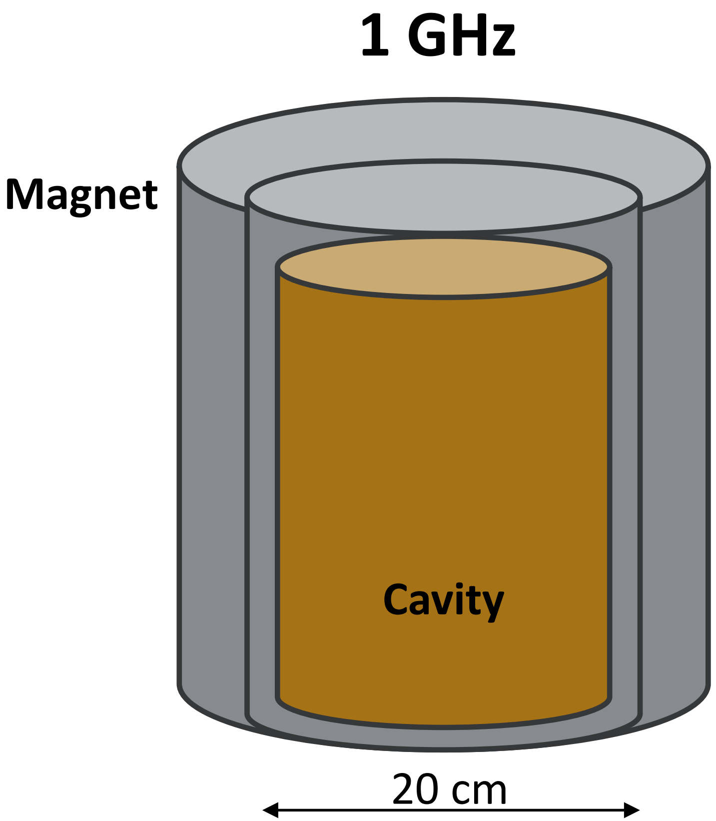


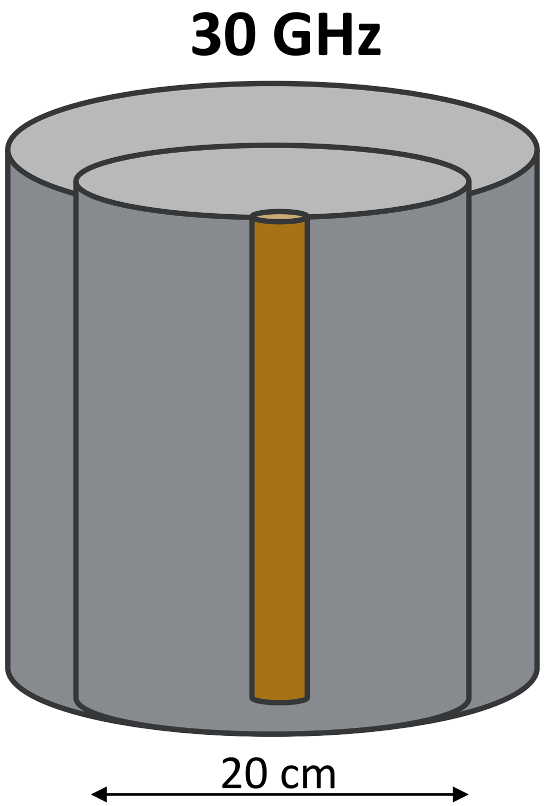
- Cryostat operating at 50mK (2025) ✓
- Two new PhD students (Oct 2025) ✓
- Cavity Fabrication and testing (Jan – Mar 2026) ✓
- Receiver Chain Hardware Arrived (Mar 2026) ✓

Assembly + data taking planned for 2026

Improved Cavities

$$R_{cavity} \sim 1/m_a \sim 1/\nu$$

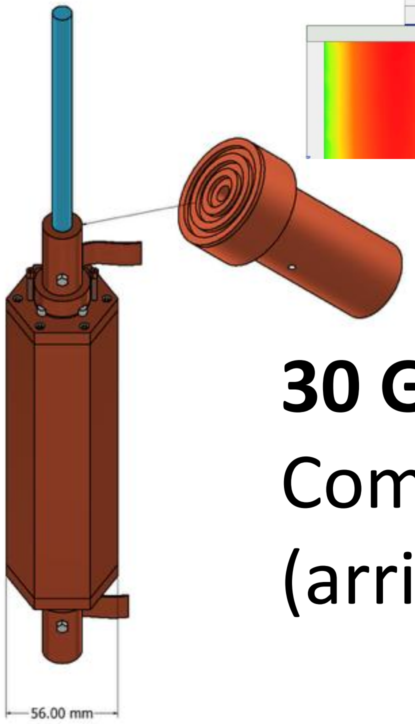


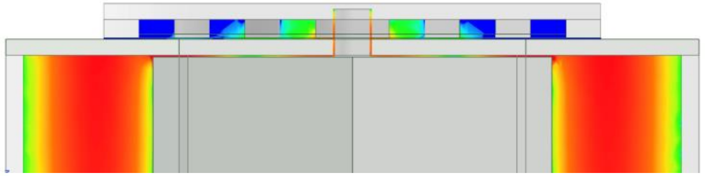


$$P_{sig} \propto g_{a\gamma\gamma} \boldsymbol{V}\, Q\, C$$

Large Volume Cavity Designs (thin shell structures)

With Nodar Rukhadze (MPhys Student)



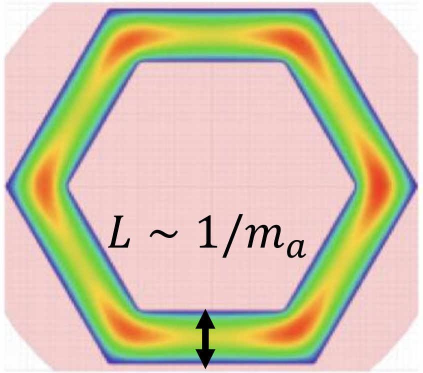


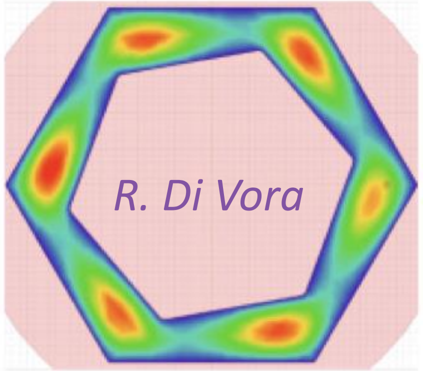
30 GHz
Compact design
(arrived on 7 Apr)

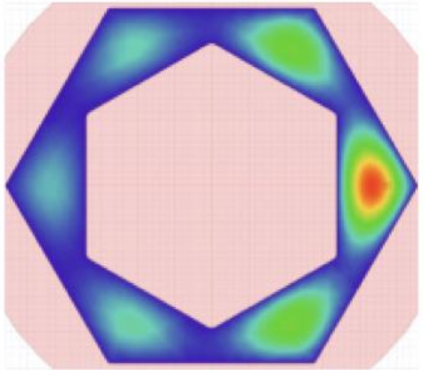
9 - 11 GHz
Toy
Prototype

Band Gap Structures (**Manchester Adaptation**)
JM, Rukhadze, McCulloch (in prep)

~ 10 GHz



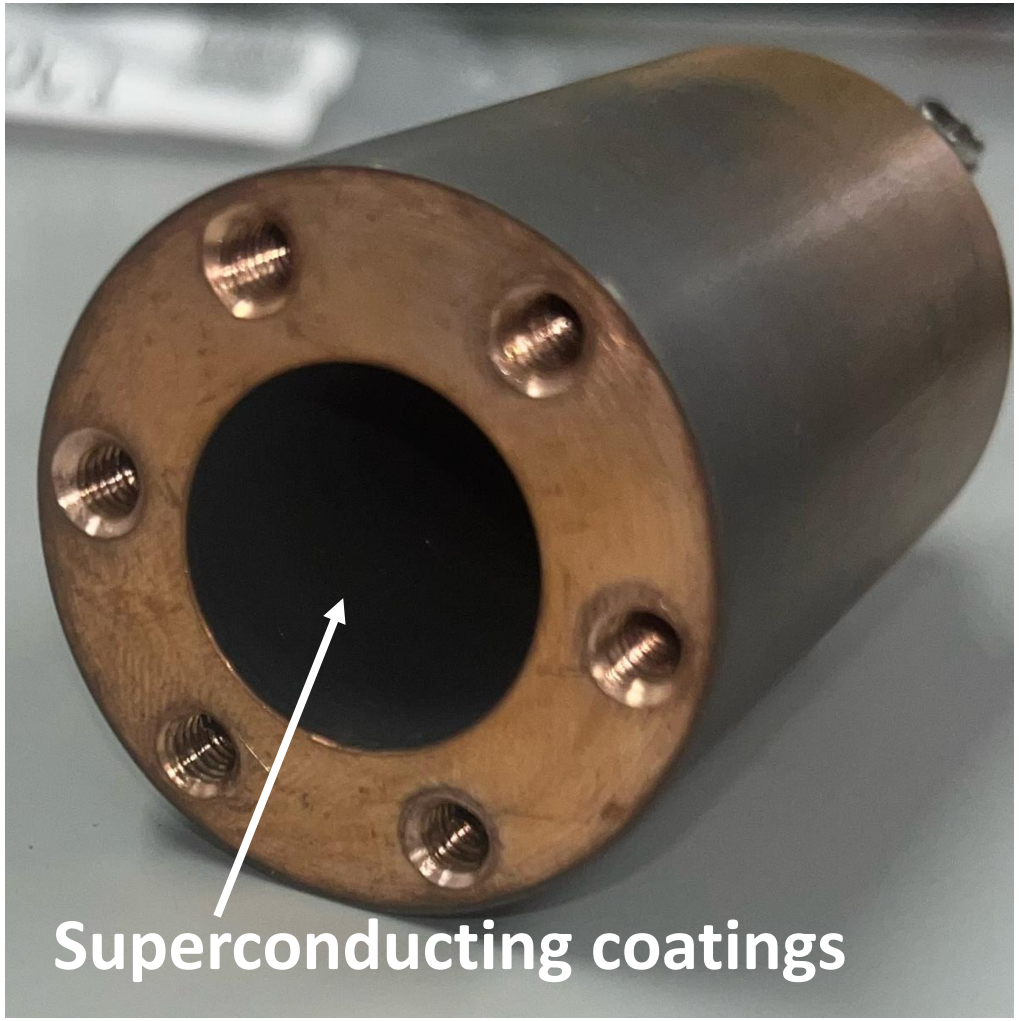




Design based on QUAX concept R. Di Vora et al PRA 23, 034047 (2025))

Reducing losses of photons (Q factor)

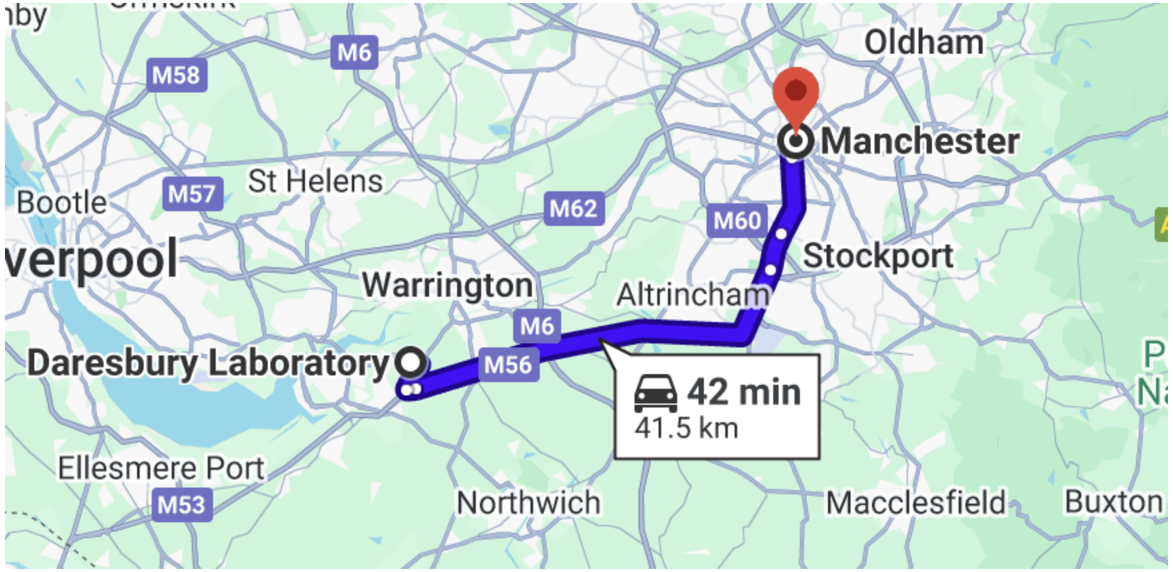
Deposition Testing and Small Prototype



Science & Technology Facilities Council
Daresbury Laboratory

Andy Blackett-May

Early stages collaboration with Manchester & Daresbury National Lab

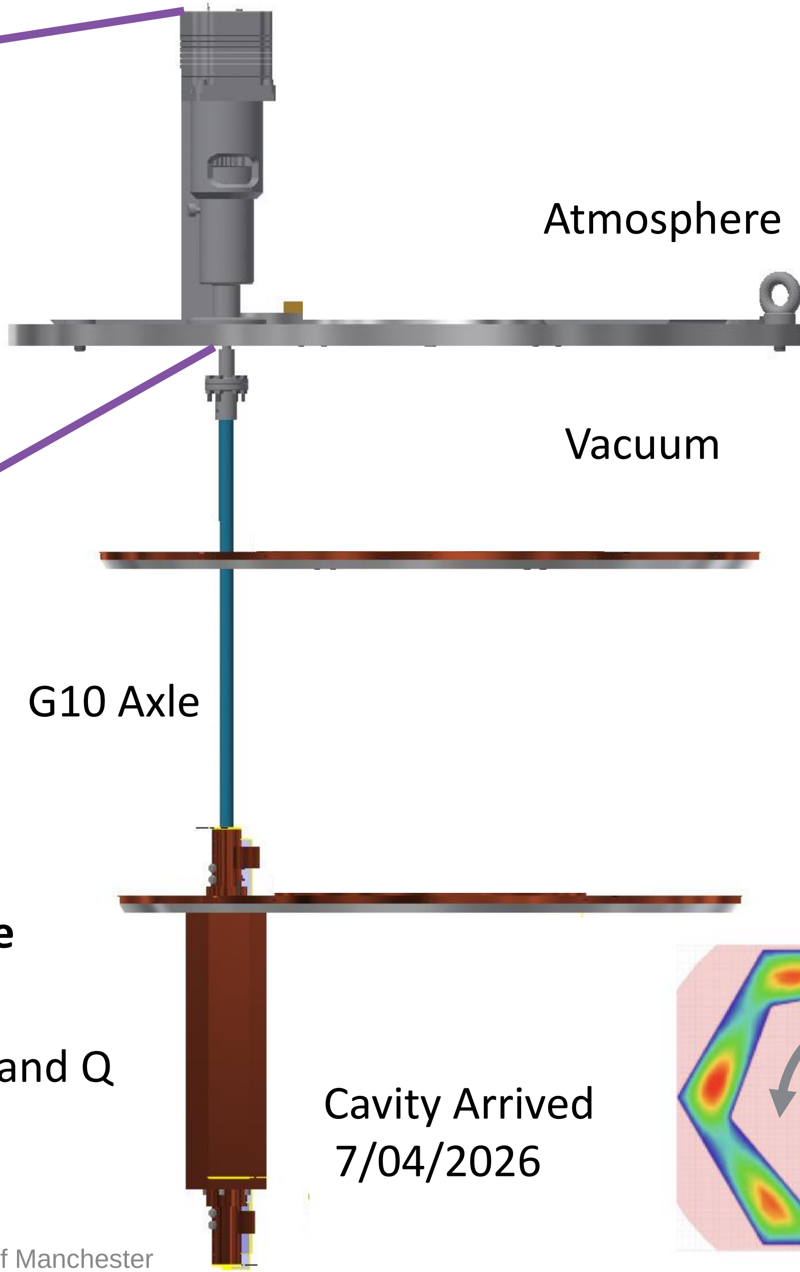


Towards Actuation and Tuning

Stepper Motor
+ rotational feedthrough

With Nodar Rukhadze
(MPhys Student)

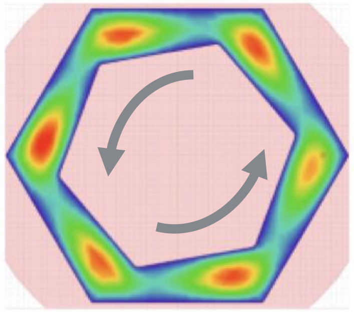
Cryostat



Possible Future Setup

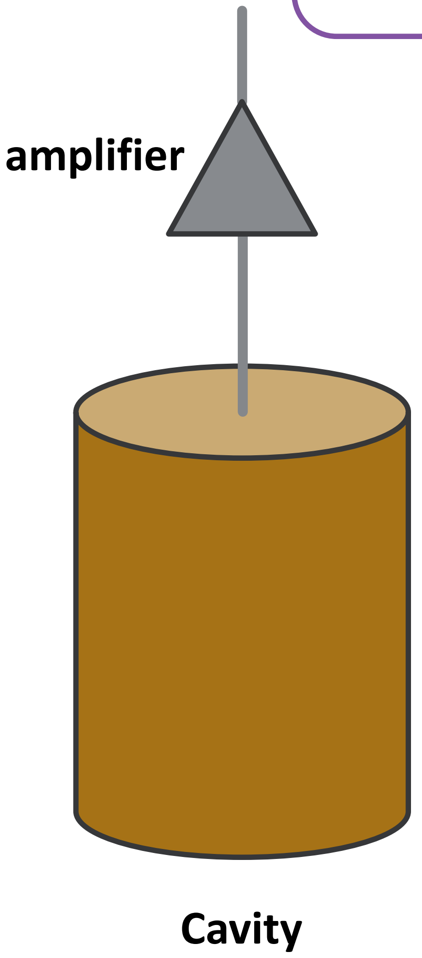
Cavity Tuning and Q Testing
@ T = 4K

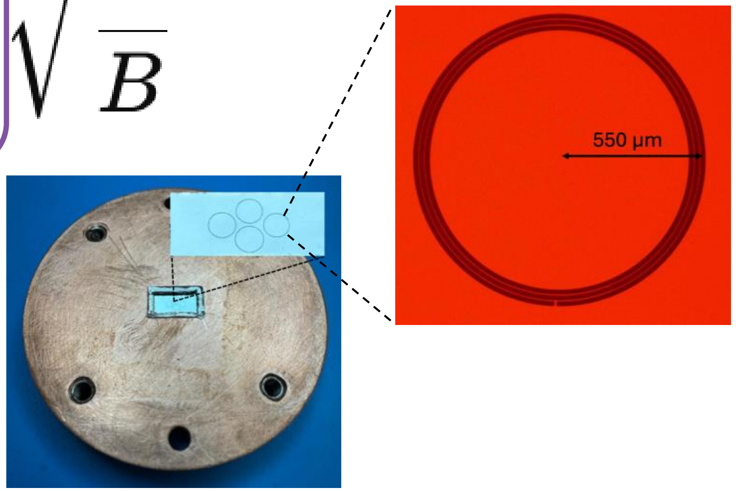
Cavity Arrived
7/04/2026



Quantum Noise Limited Amplifiers

$$\mathrm{SNR} = \boxed{\frac{P_{\mathrm{sig}}}{k_B T_{\mathrm{sys}}}} \sqrt{\frac{\tau}{B}}$$

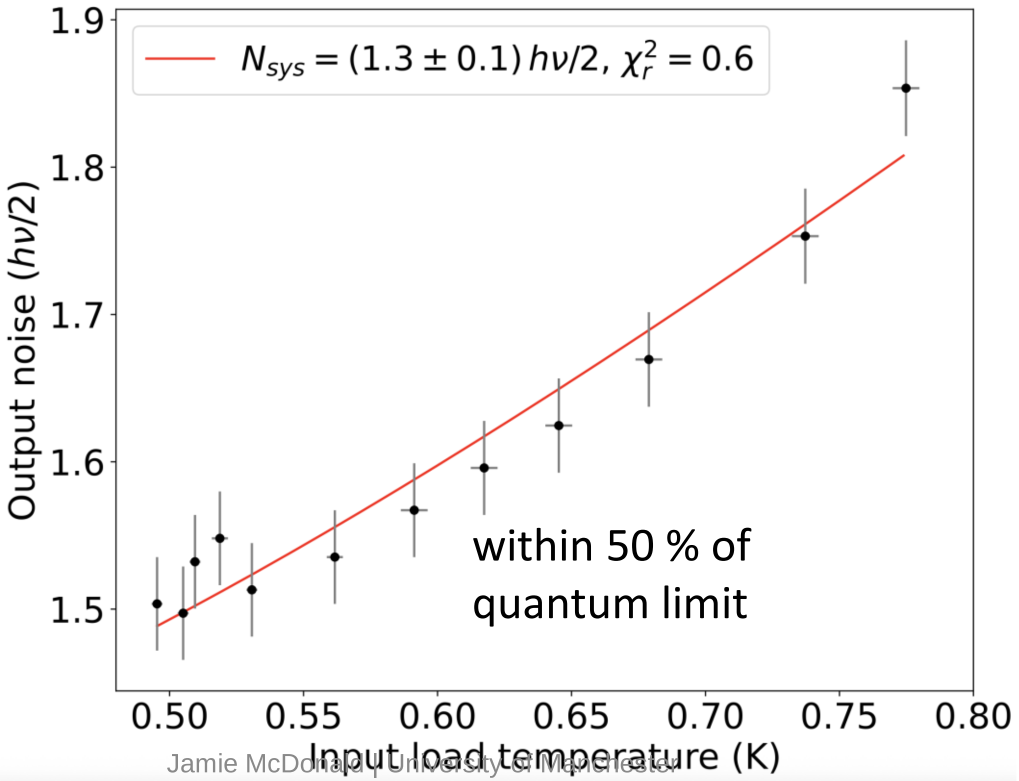




A cm-wave quantum noise limited resonant superconducting parametric amplifier

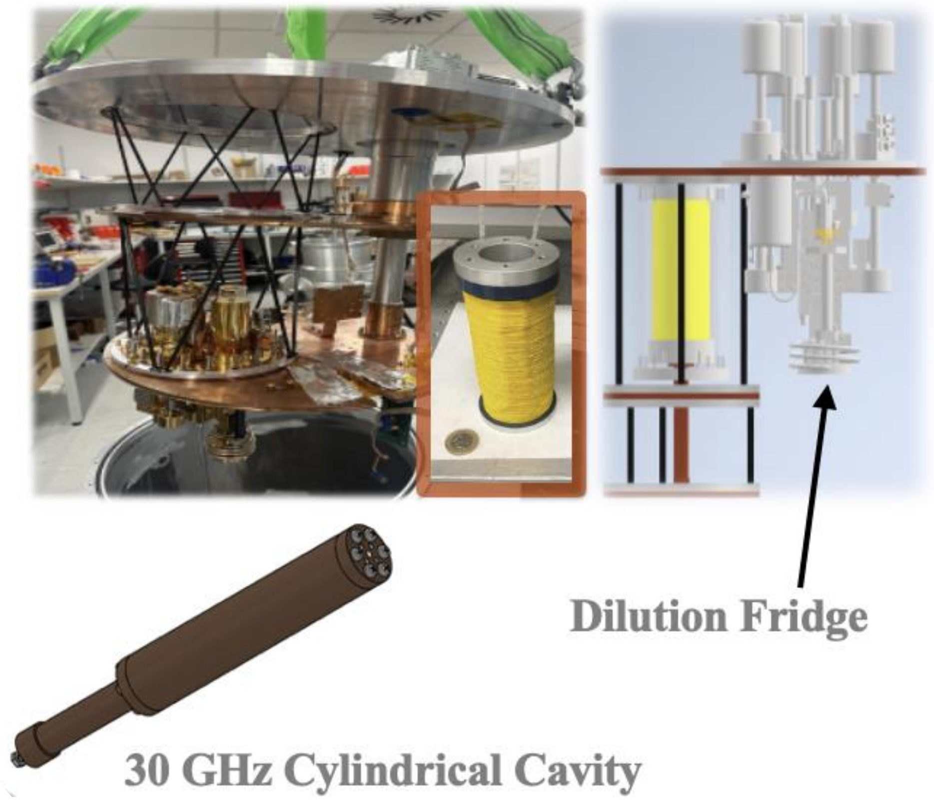
V. Gilles,* T. Sweetnam,† B. Mohammadian, M. A. McCulloch, and L. Piccirillo
Department of Physics and Astronomy, The University of Manchester, Manchester, United Kingdom
(Dated: January 15, 2026)

Noise

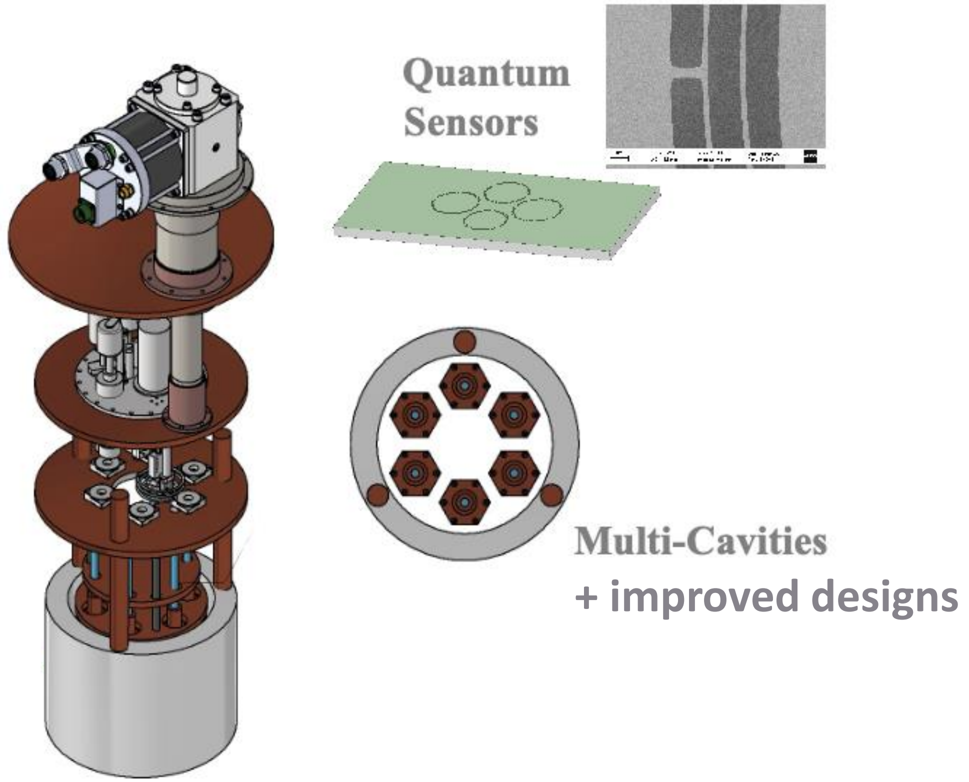


A possible view of the future:

Existing Pathfinder (2026)



Possible next phase experiment



8 Tesla
20 cm bore

Summary

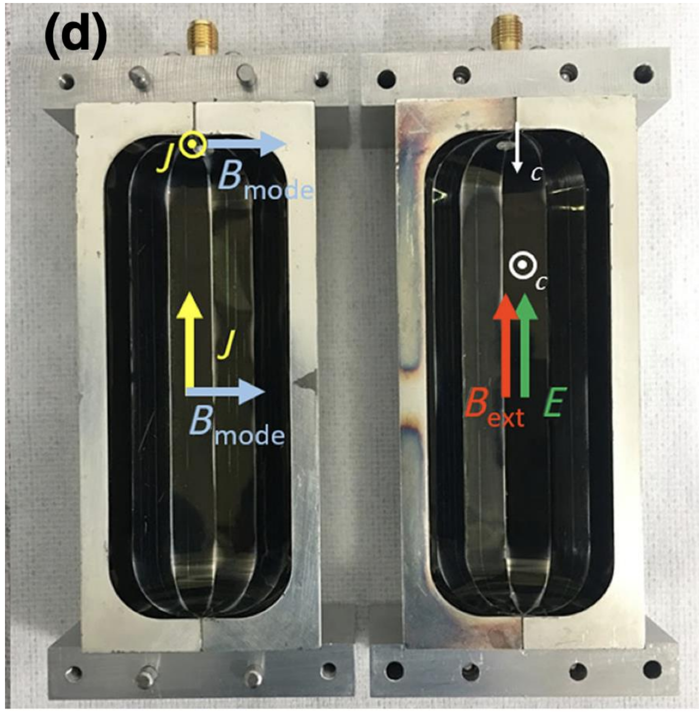
- Pillbox Cavity fabricated, testing underway
- Quantum noise limited amplifiers demonstrated
- Improved cavity designs in progress
- Data analysis and acquisition under development
- Construction and data taking with path finder to begin in 2026,

Thank You

Backup Slides

Increased Q under high B

Q = 300,000 @ B = 8 T



Superconducting Tapes

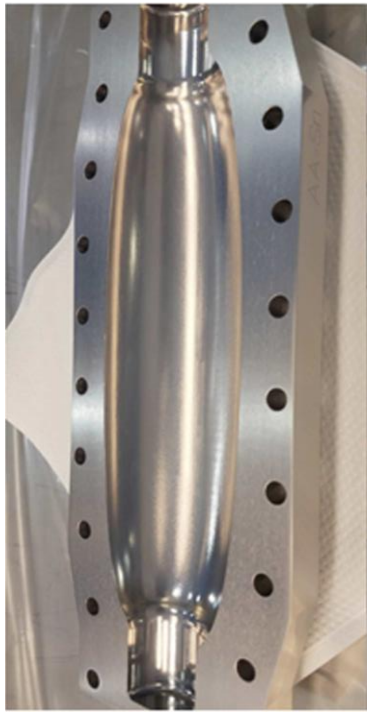
Ahn, J., *et al.*
Phys. Rev. Applied **17**, L061005 (2022)

Q =720,000

Sapphire Inserts

D Alesini et al
Nucl. Instrum. Meth.
A 985 (2021) 164641

Q = 1,000,000
@ B = 6 Tesla



Superconducting Films

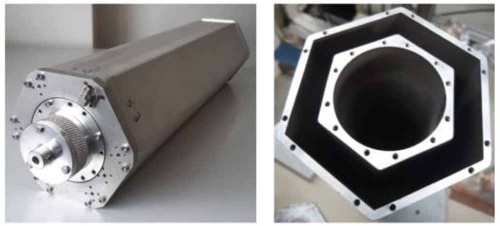
Posen et al
Phys. Rev. Applied
20, 034004 (2023)

Marconato et al
IEEE Trans. Appl. Supercond.
34(7) October 2024

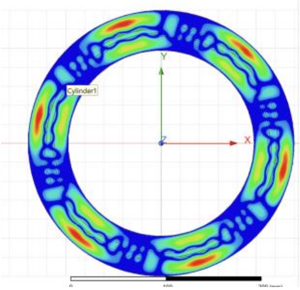
Science & Technology Facilities Council
Daresbury Laboratory
Manchester + Early Collab with Daresbury Lab

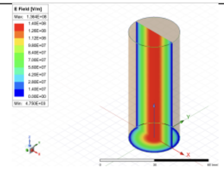
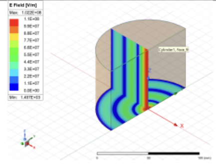
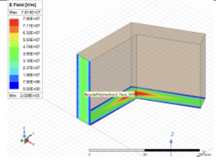
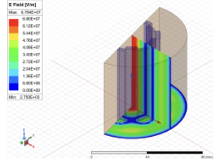
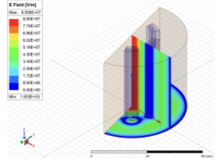
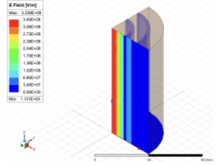
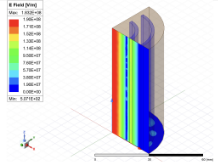
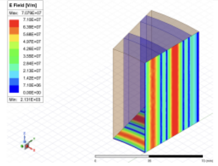
Improved Cavity Designs

Case Study



R. Di Vora et al PRA 23, 034047 (2025))



Design Type	Picture	Freq (GHz)	V (m^3)	C	Q	Mode	FoM
Empty Cylinder		8.03	4.56×10^{-5}	0.692	16068	TM010	1.60×10^{-5}
Empty Cylinder		8.03	5.93×10^{-4}	0.0534	40430	TM030	4.06×10^{-5}
Hexagonal		8.62	9.54×10^{-4}	0.756	10663	TM010	5.55×10^{-3}
Korean Cylinder (Closed)		7.20	4.51×10^{-4}	0.377	31847	TM030	9.21×10^{-4}
Korean Cylinder (Open)		6.83	4.51×10^{-4}	0.405	36963	TM030	1.23×10^{-3}
Italian Cylinder (Closed)		11.1	1.88×10^{-4}	0.0393	105381	TM030	5.75×10^{-6}
Italian Cylinder (Open)		10.5	1.88×10^{-4}	0.0363	92515	TM030	4.30×10^{-6}
Basic Ring†		9.70	2.79×10^{-3}	0.296*	44805*	TM050	3.05×10^{-2}

Scan Rate (m^3)

$$\frac{df}{dt} \propto (VC)^2 Q_c$$

With MPhys student
Hong-Kai Tan
(now PhD at Warwick)

Amplifier Gain