Progress Report on the QSHS Axion Search

QSHS

UKRI Science and Technology Facilities Council

Lancaster University
The University Of Sheffield.
NPL National Physical Laboratory
University of Oxford
Royal Holloway University of London
UCL

+ ADMX

Ed Daw, on behalf of the Quantum Sensors for the Hidden Sector collaboration

QCD Axions

Strong CP problem

Standard model symmetry group is

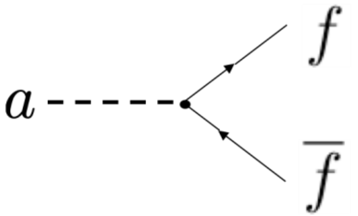
$$\underbrace{SU(3)}_{\text{NON-ABELIAN}} \times \underbrace{SU(2)}_{\text{NON-ABELIAN}} \times \underbrace{U(1)}_{\text{ABELIAN}}$$

CP CONSERVING!	CP VIOLATING	CP CONSERVING

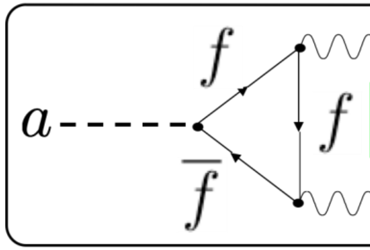
Neutron electric dipole moment $< 10^{-26}\ \mathrm{e-cm}$

Peccei Quinn mechanism: CP conserved below a symmetry breaking energy scale f_{PQ}

Breaking of the Peccei Quinn symmetry yields axions



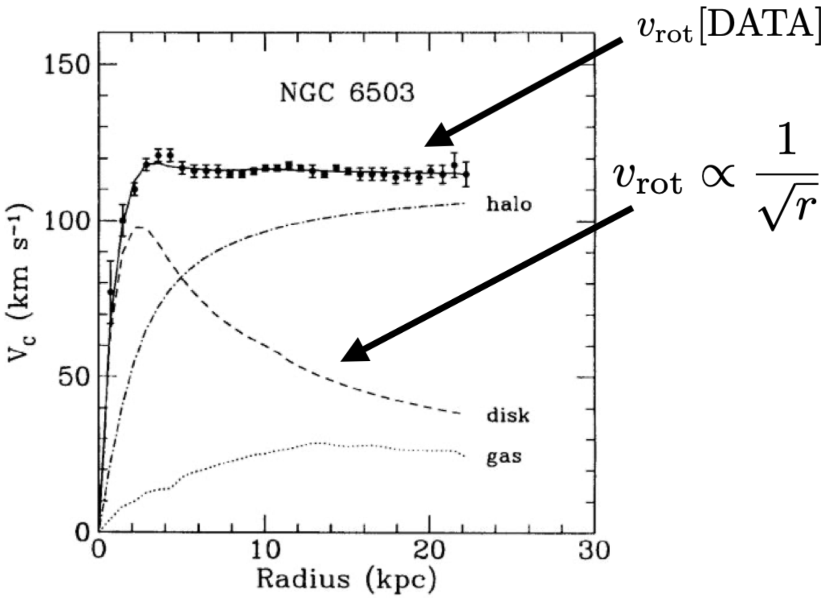
$\Longrightarrow$

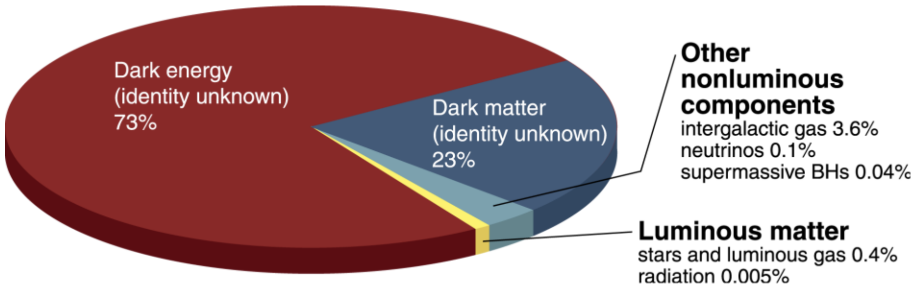


$g_{a\gamma\gamma} \propto m_a$

$$\frac{m_a}{m_\pi} \simeq \frac{g_{a\gamma\gamma}}{g_{\pi\gamma\gamma}} \simeq \frac{f_{\rm QCD}(\sim 100\,\mathrm{MeV})}{f_{\rm PQ}}$$

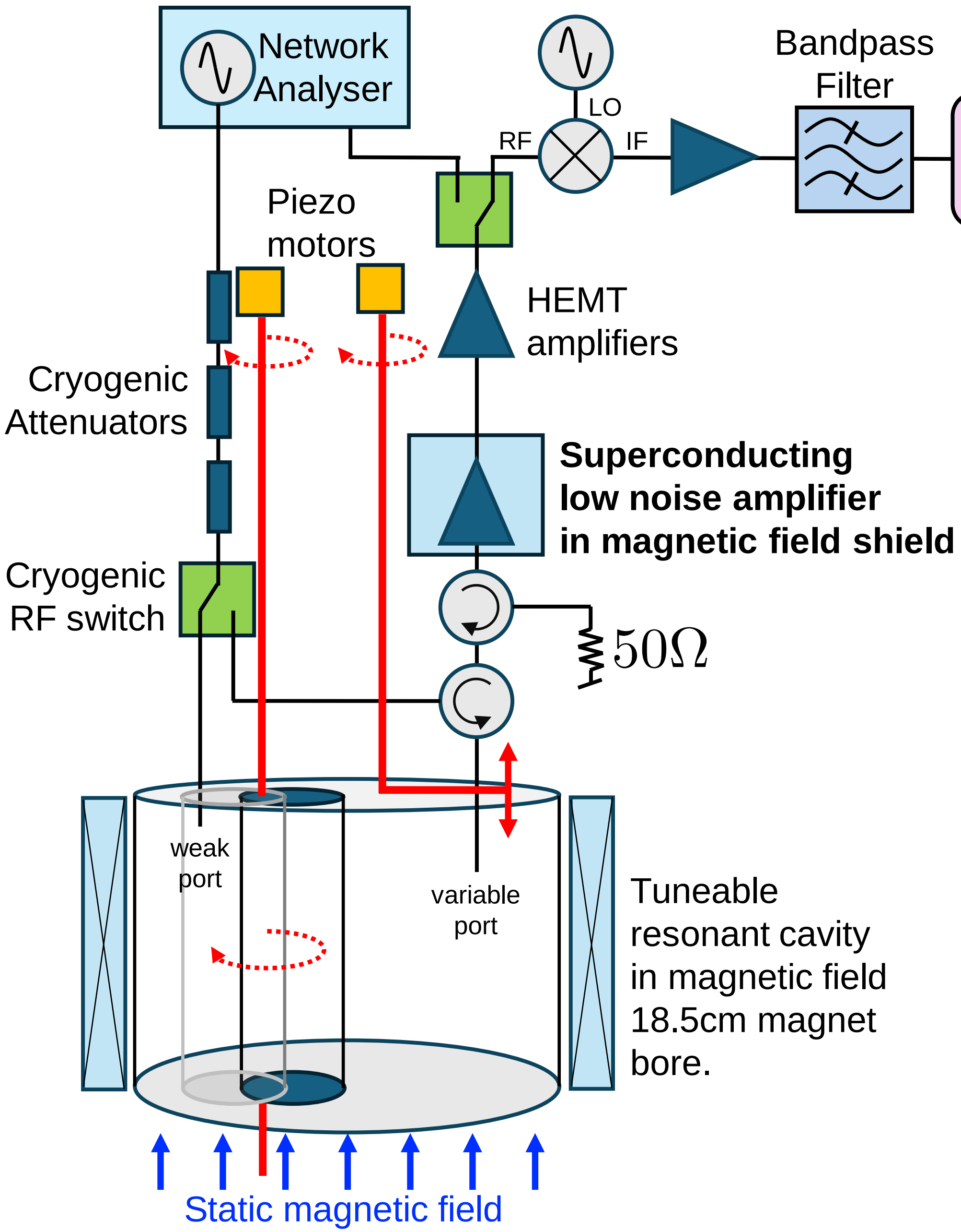
Dark matter problem

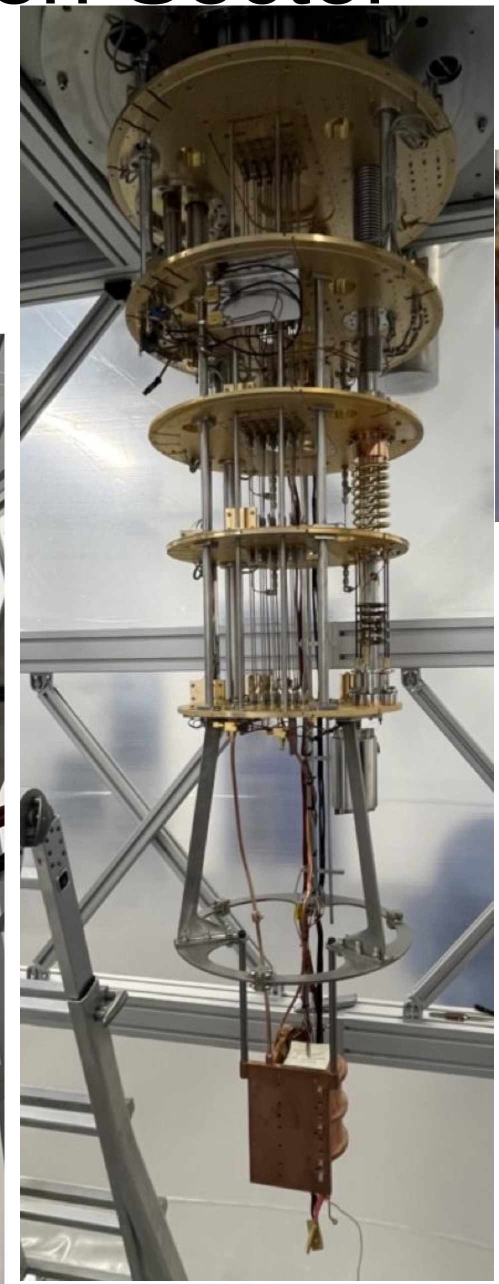




QCD axions are **wave-like dark matter**; at a mass of a **micro-eV**, dark matter axions thermalized locally in our halo have **Debroglie wavelengths of hundreds of metres**

Quantum Sensors for the Hidden Sector



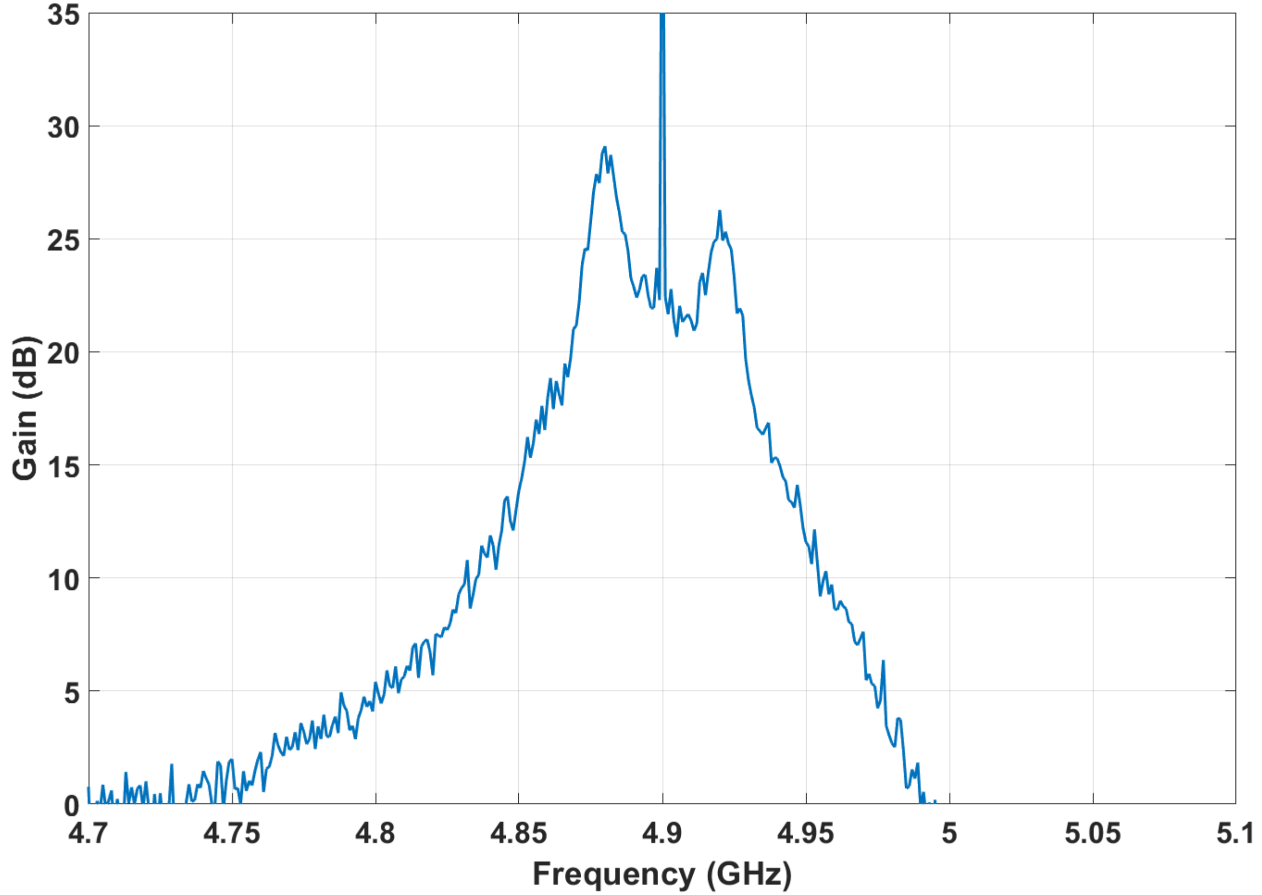


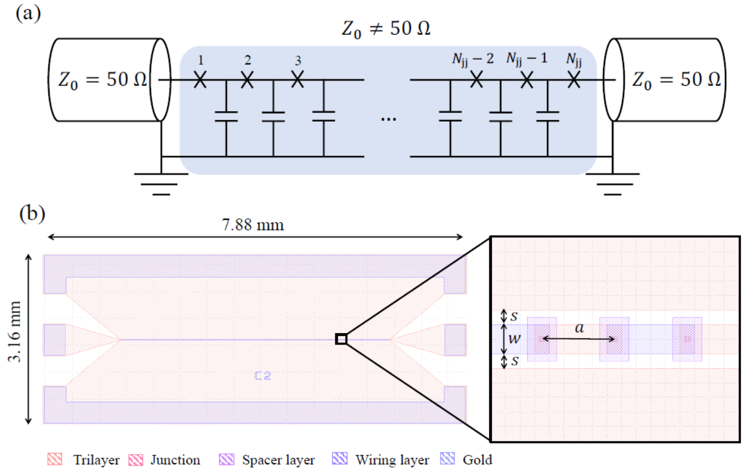
Field Shield design, Ed Laird (Lancaster)

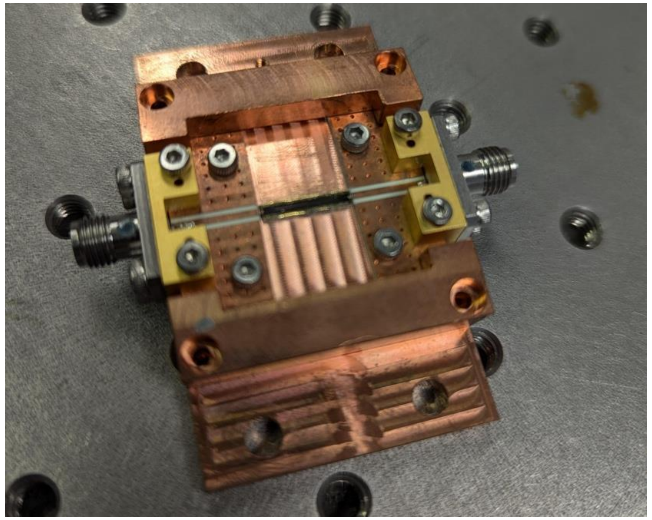
Standing-Wave Parametric Amplifier (SWPA)

Boon Kok Tan, Senior Research Fellow and Ph.D. student Javier Navarro Montilla

Narrow > 20 dB gain of ~60 MHz





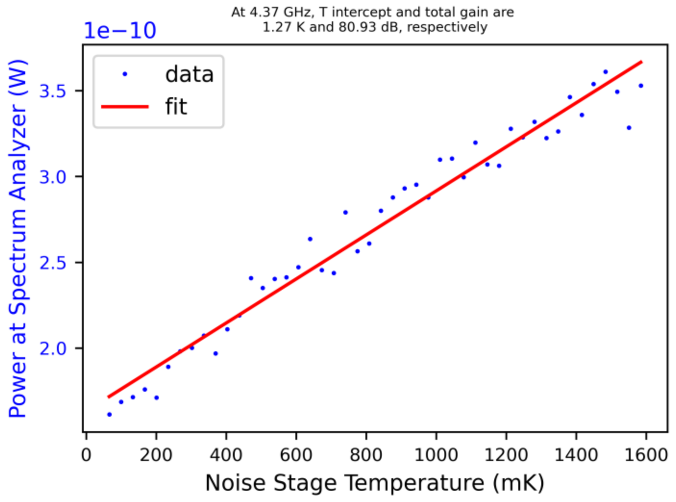


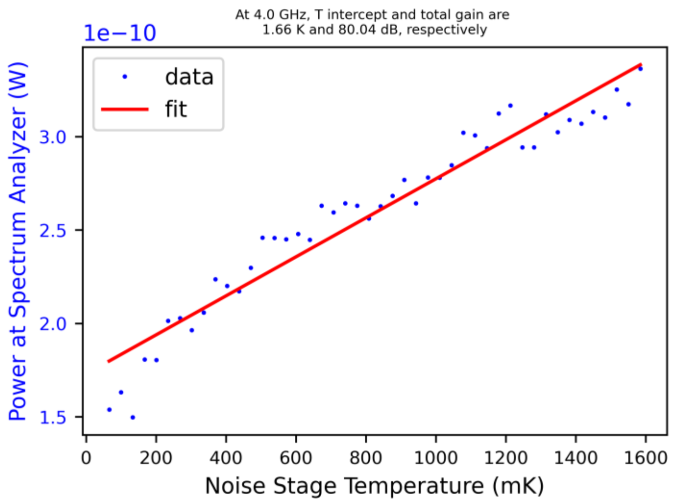
Characterisation of ‘Snail’ VTT TWPA - Lancaster

Joshoua Esmenda –postdoctoral associate

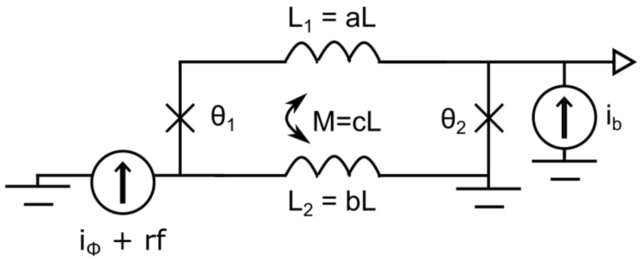
Signal Frequency (GHz)	Bypass		Parameters 0 Pump=13 GHz, -61 dBm, BC = 670 uA				Parameters 1 Pump=12.4 GHz, -61 dBm, BC = 695 uA				Parameters 2 Pump=12.4 GHz, -61 dBm, BC = 705 uA			
	T_{bypass} (K)	G (dB)	T_{total} (K)	G (dB)	T_{TWPA} (K)	G_{TWPA} (dB)	T (K)	G (dB)	T_{TWPA} (K)	G_{TWPA} (dB)	T (K)	G (dB)	T_{TWPA} (K)	G_{TWPA} (dB)
4.00	9.3	69.34	1.91	79.05	0.915779	9.71	1.7	81.08	1.077007	11.74	1.66	80.04	0.868442	10.7
4.37	9.94	69.38	2.4	79.3	1.38752	9.92	1.27	80.93	0.574357	11.55	1.75	81.2	1.096288	11.82
5.00	8.75	68.62	1.85	80.18	1.239047	11.56	2.64	79.17	1.869082	10.55	2.13	80.51	1.56375	11.89
6.00	7.55	66.93	1.72	77.79	1.100635	10.86	1.85	75.81	0.872882	8.88	4.93	77.36	4.246172	10.43
6.20	7.94	66.79	1.95	76.85	1.166894	10.06	NA	NA	NA	NA	NA	NA	NA	NA
8.00	7.85	67.76	1.88	81.05	1.511981	13.29	3.61	81.64	3.28873	13.88	4.58	79.71	4.078963	11.95

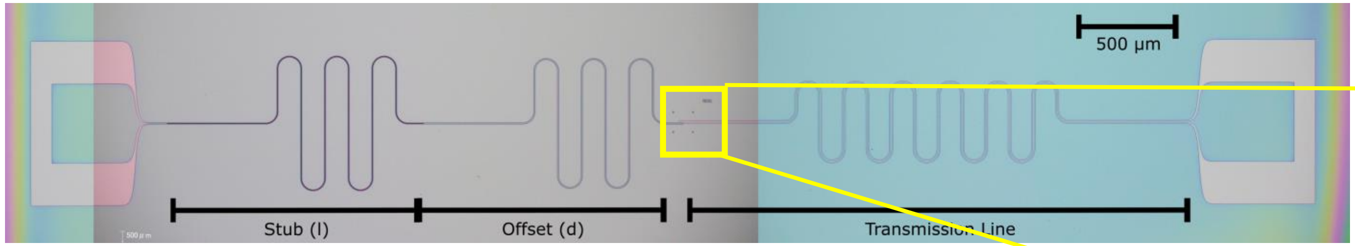
Through the y-factor method, the noise characteristics of the SNAIL JTWPA from VTT were obtained. This was done by heating a carefully calibrated noise stage from 30 mK to 1600 mK at the input of the TWPA while recording the power spectrum of the TWPA output. The same procedure is done for a bypass configuration, where the TWPA is replaced by a through line. Using different optimal parameters for the pump and bias current, the noise temperature obtained was as low as 600 mK on certain signal frequencies.

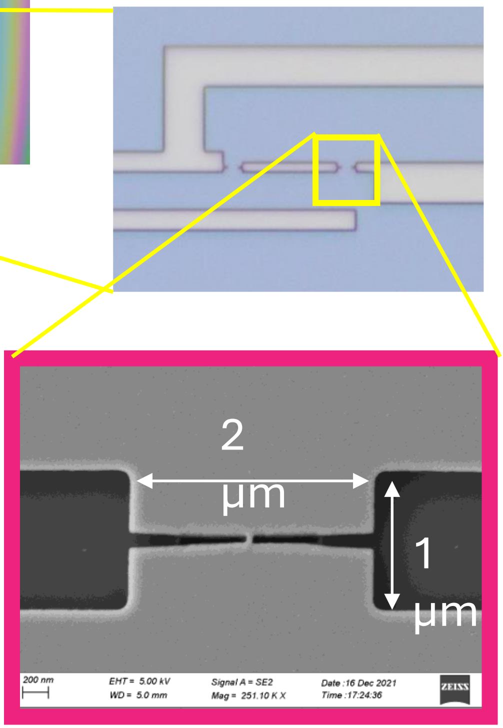


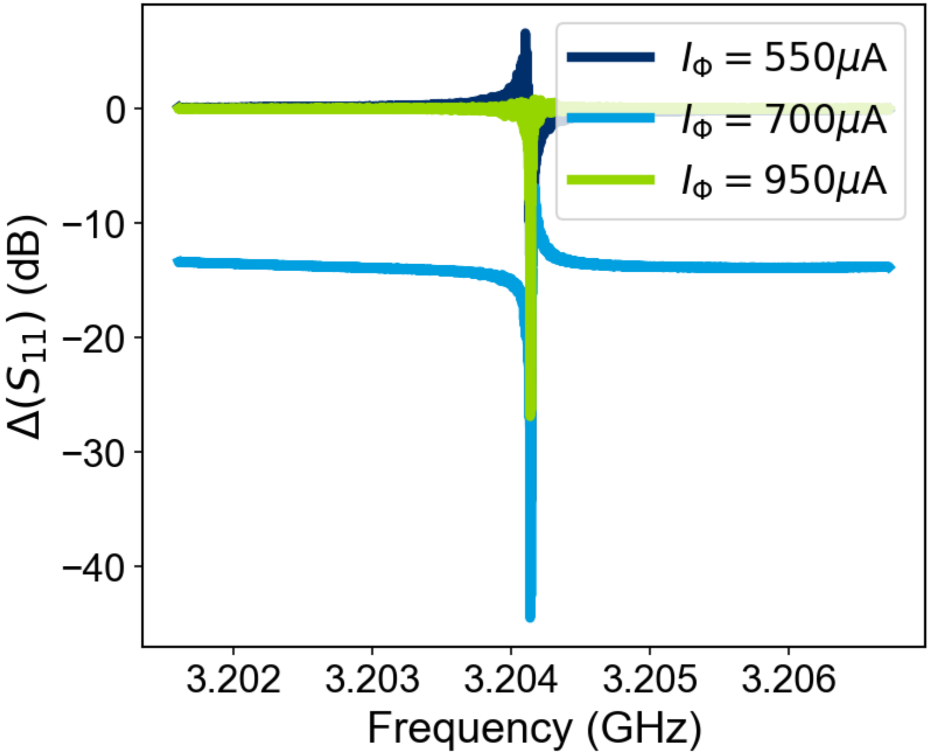


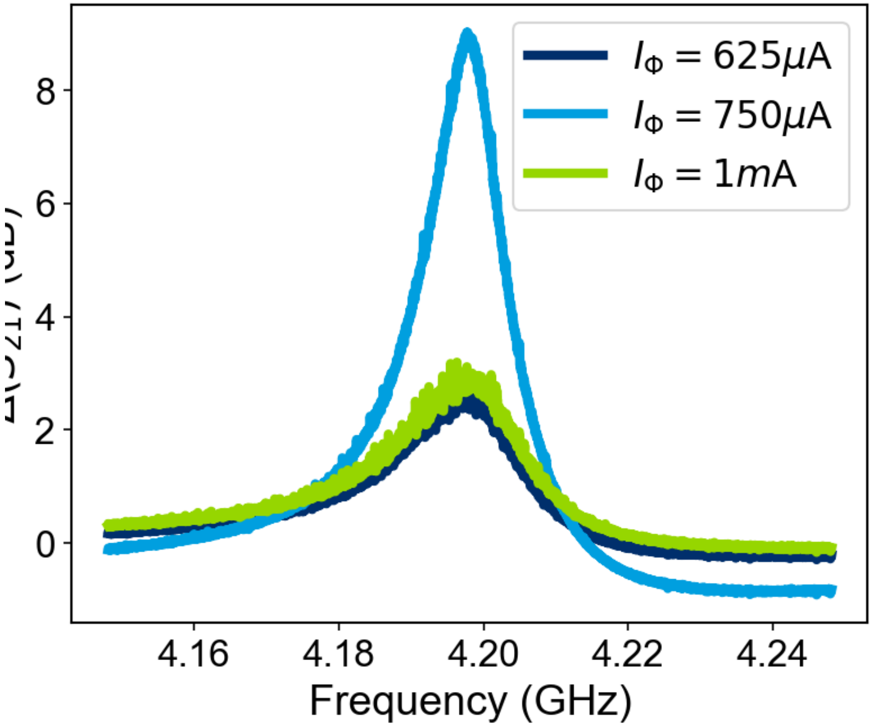
SLUG loaded SQUID amplifiers











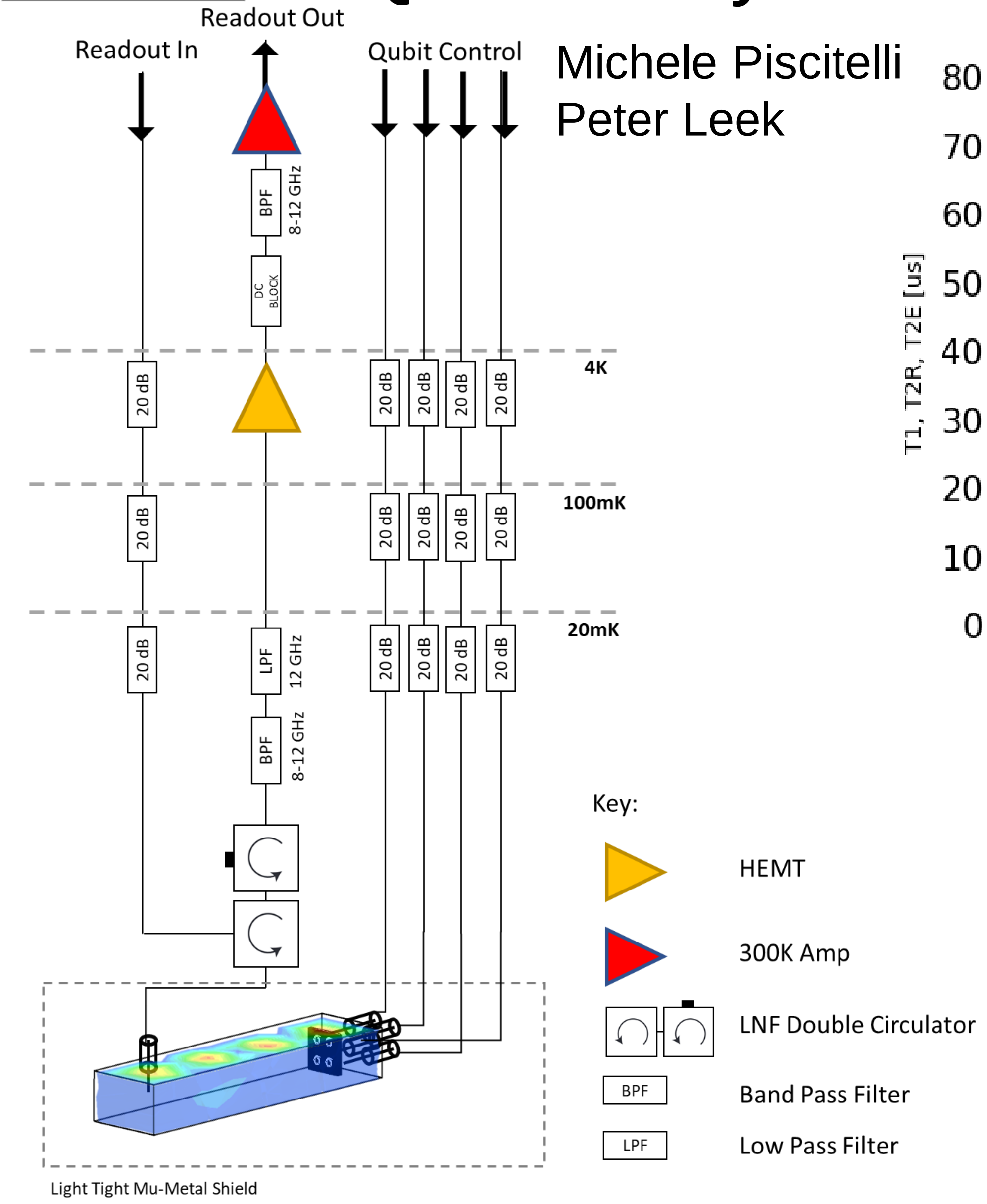
Ling Hao (NPL)
Gemma Chapman (NPL)
Ed Romans (UCL)
Thomas Godfrey (UCL)

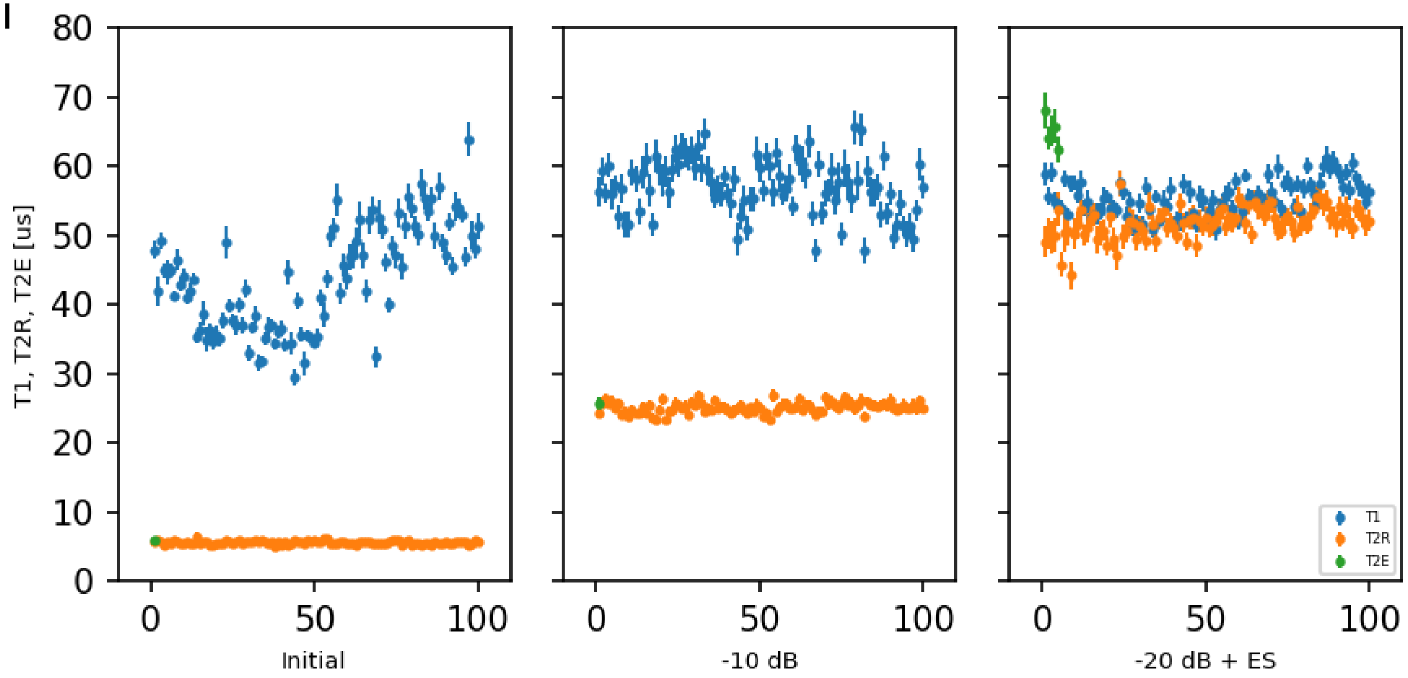
T = 6.4 K, P_{in} = -40 dBm

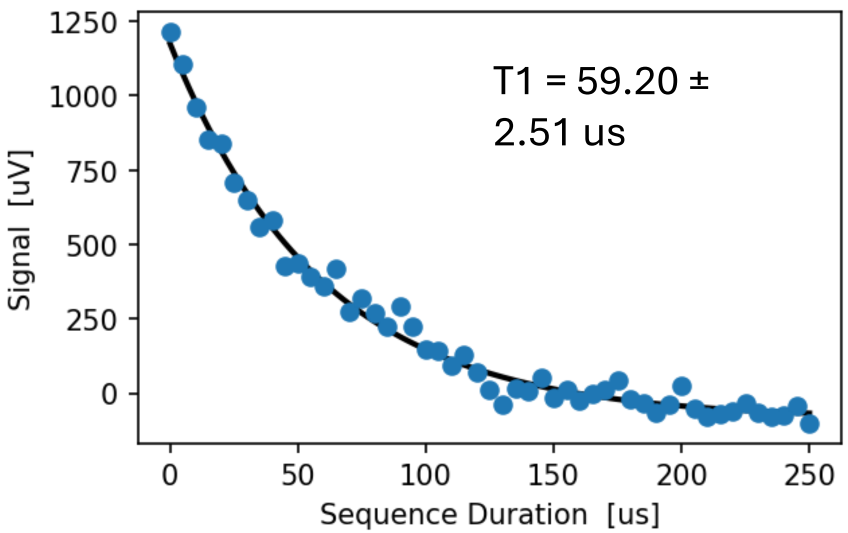
L = 3.1 pH, R = 5.8 Ω, V_Φ = 0.14 mV/Φ_0

Qubit array sensors for fundamental physics

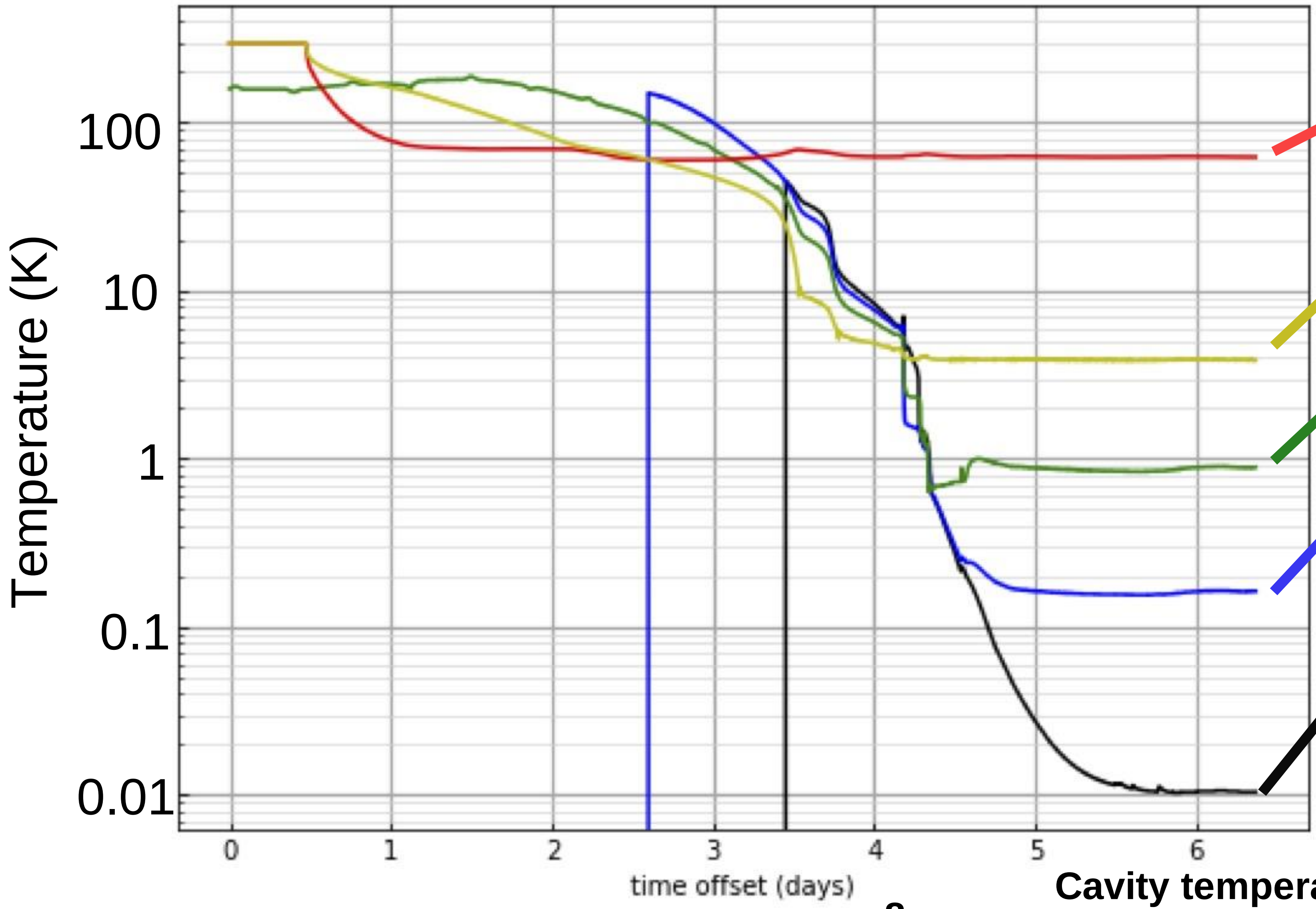
Michele Piscitelli
Peter Leek

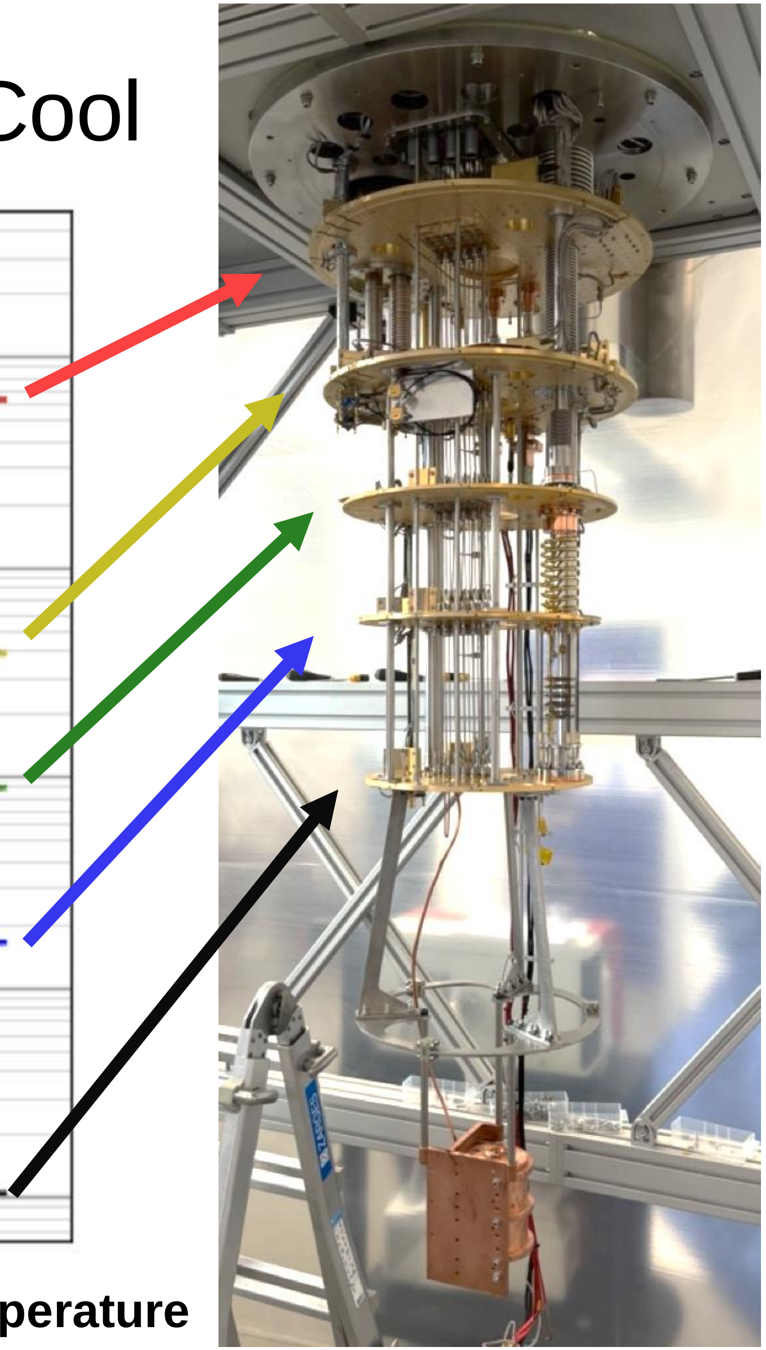






Sheffield Test Stand, First Cavity Cool





Cavity temperature sensor at 18mK

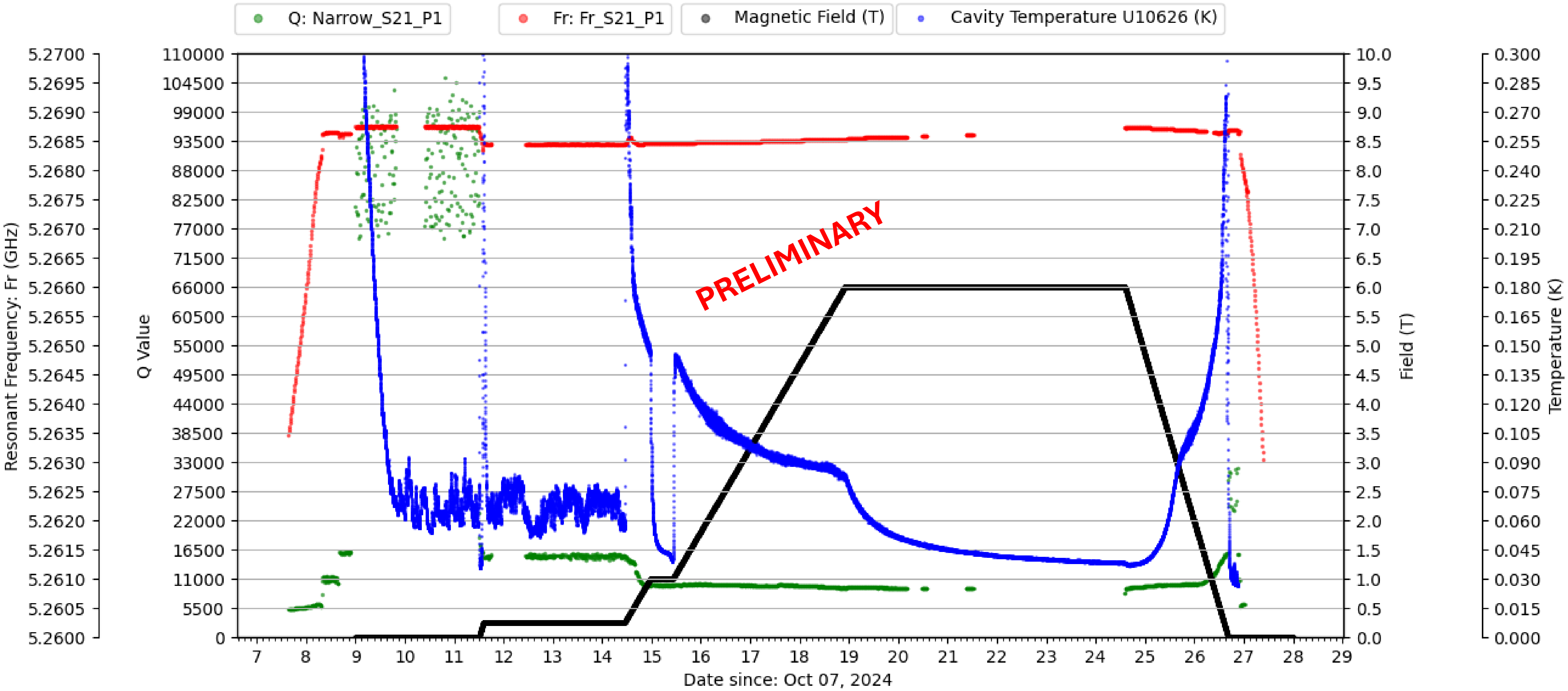
Current Magnet Status

- Maximum field with initially delivered magnet was 6T. Design was for 8T.
- Quench at higher fields. Suspected to be caused by mechanical deformation of outer shield coil due to force on windings from inner coils.
- New formerless coil now fabricated at Oxford Instruments. Tests this month.

Gu Yuwei
Magnet Engineer, Oxford Instruments

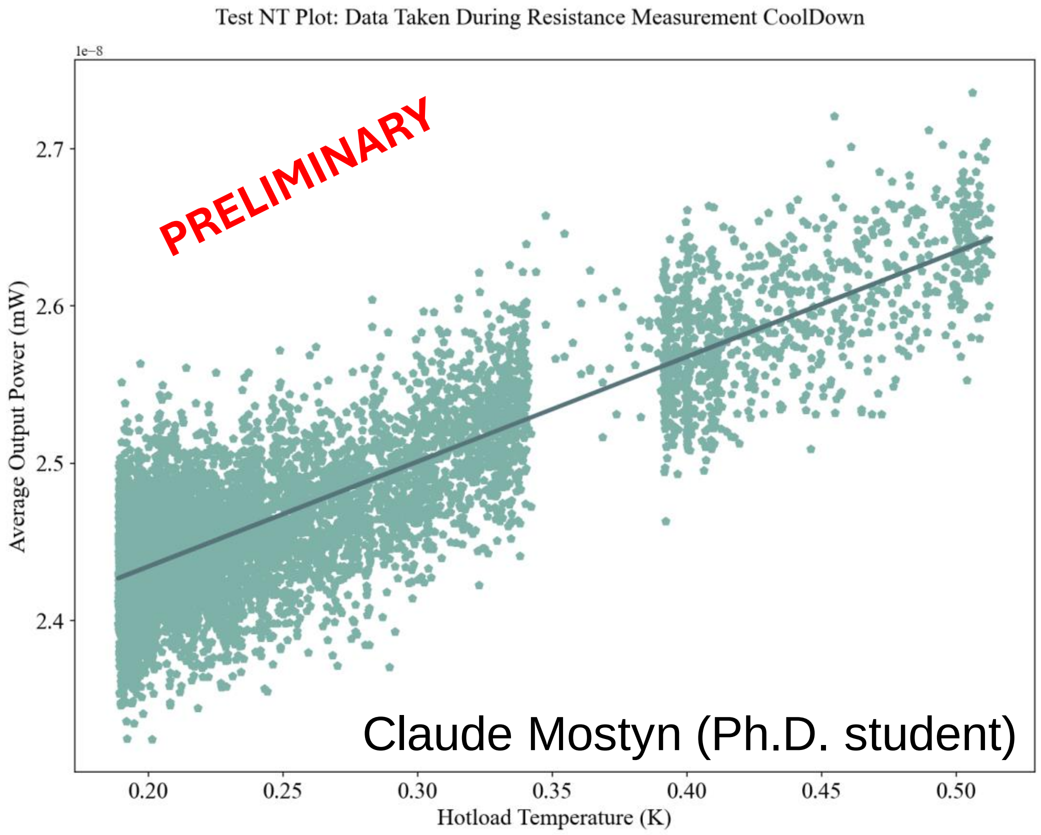
Phil Meeson
RHUL

Characterisation of Superconducting Resonators in magnetic fields



Paul Smith – Postdoctoral Associate, Nick Du (Livermore Lab research fellow, ADMX collaborator)

Preliminary noise temperature tests, Antenna drive



First hot-cold load measurement of stage-2 HEMT amplifier noise temperature was 3.5K. Attenuation of cable between noise source and amplifier at -4.6dB was too high. Modify with a single length of NbTi coax.

Limited torque from Attocube piezo actuators; about 10N-cm. Low friction rotation to linear motion actuator for antenna just fabricated. Mitch Perry (Ph.D. student)

Conclusions and Future Work

- Fridge and cavity installed. Cavity temperature 20mK.
- Several low noise amplifiers are far advanced in development at Oxford, Lancaster, UCL, NPL.
- 6T magnet installed. Can raise field and keep cool.
- Upgraded shield coil fabricated, under test, for 8T field.
- Currently commissioning motor drives for cavity tuning.
- Tests with ADMX of NbSn coated tuning rod indicate that the coating is superconducting in 6T field.
- First noise temperature measurements on HFET amplifiers performed in-situ.
- First axion search using QSHS will happen in 2025!