Istituto Nazionale di Fisica Nucleare

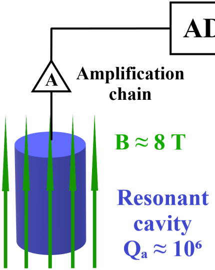
Laboratori Nazionali di Legnaro

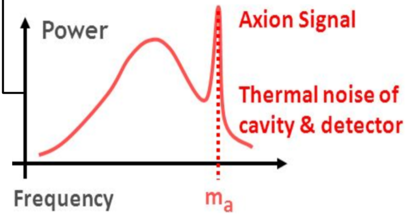
Very high Q-factor dielectrical microwave resonator in high magnetic field for axion dark matter search

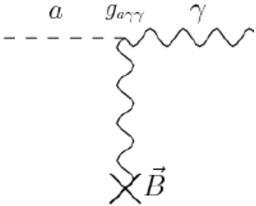
Raffaele Di Vora

On behalf of the QUAX collaboration

The haloscope: a resonant axion dark matter detector







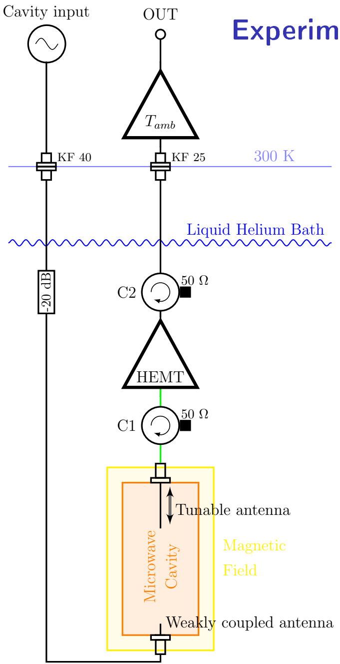
Expected signal and noise

$$P_{axion} \approx 2.2 \cdot 10^{-24}\, W \left(\frac{V}{0.0268\, l}\right)\left(\frac{B}{8\ T}\right)^2\left(\frac{C}{0.59}\right)\left(\frac{g_\gamma}{-0.97}\right)^2 \cdot$$

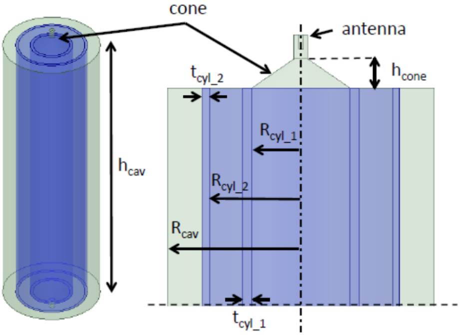
$$\cdot \left(\frac{\rho_a}{0.45\ GeV\ cm^{-3}}\right)\left(\frac{\nu_c}{9.067\ GHz}\right)\left(\frac{Q_L}{201000}\right)$$

$$\sigma_{P_{noise}} \sim k_B T_{sys}\sqrt{\frac{\Delta\nu}{\Delta t}} = 2.2 \cdot 10^{-23}\, W \left(\frac{T_s}{1\ K}\right)\left(\frac{\Delta\nu}{9\ kHz}\right)^{\frac{1}{2}}\left(\frac{3600\ s}{\Delta t}\right)^{\frac{1}{2}}$$

Experimental setup and cavity model

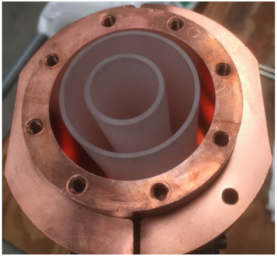


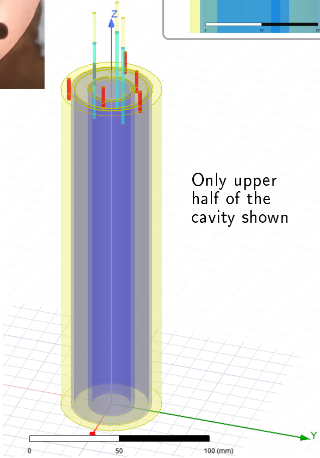
R_{cav}	28.55
R_{cyl_1}	10.88
R_{cyl_2}	20.90
t_{cyl_1}	2.35
t_{cyl_2}	1.94
h_{cone}	6.00
h_{cav}	420

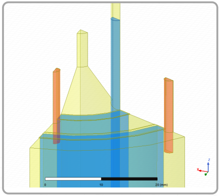


Cavity	V	C_{nml}	$V_{eff} = C \cdot V$	ν_{cav}
Cu	80.6 cm^3	0.69	55.6 cm^3	10.4 GHz
This work	*1056 cm^3*	*0.033*	*34.7 cm^3*	*10.35 GHz*

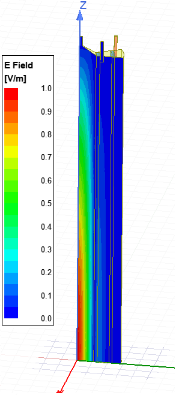
Electric field and surface loss for the TM_{010} mode

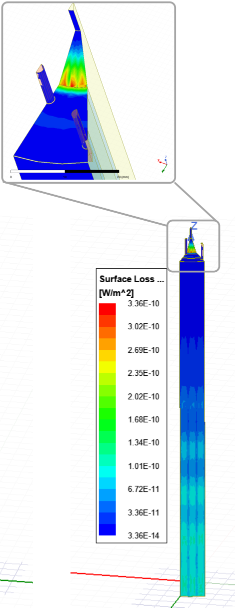




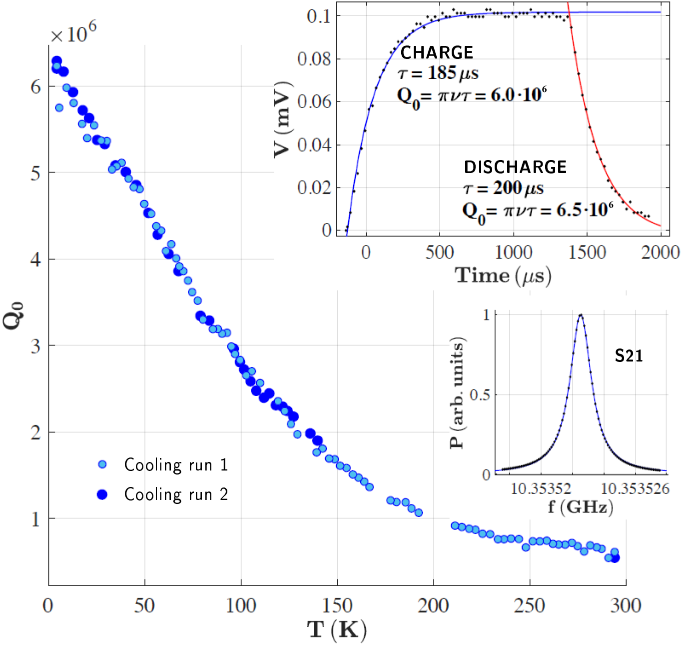


Only upper half of the cavity shown

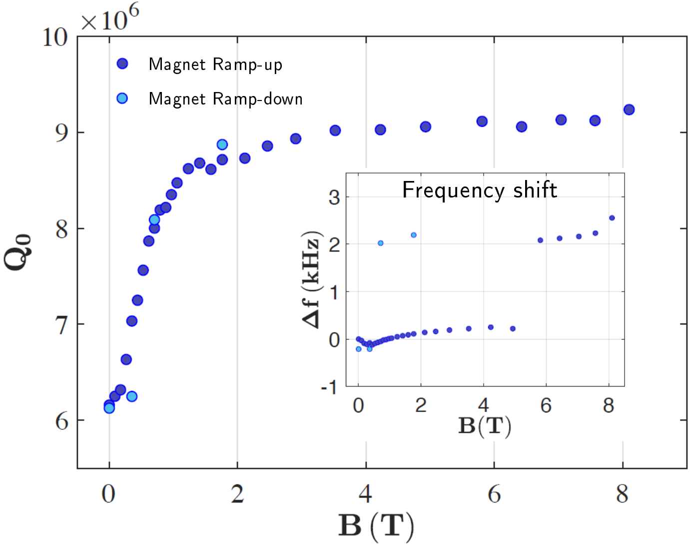




Cavity coolings: Q factor vs temperature

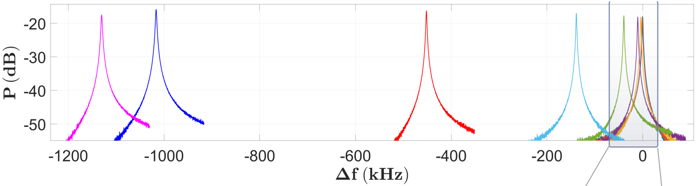


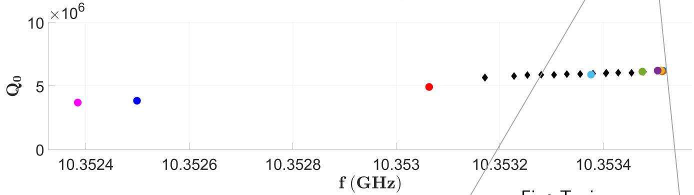
Measurement at 4 K: Q factor vs magnetic field

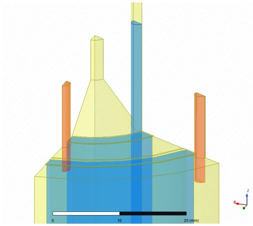


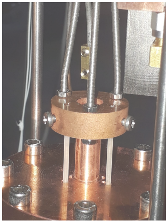
Cu magnetoresistance measurements @CAPP: slight surface conductivity increase ($\approx 3\%$)... instead about $\approx 50\%$ increase seen!

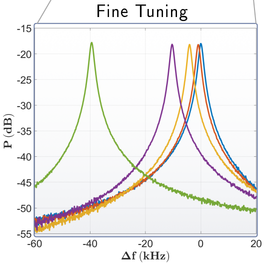
Mechanical tuning demonstration



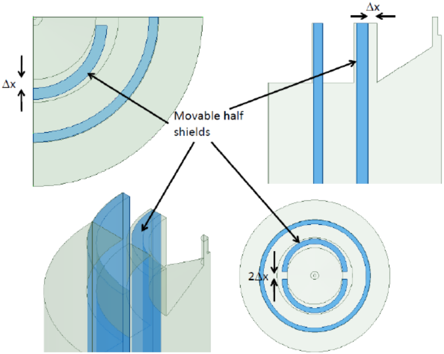


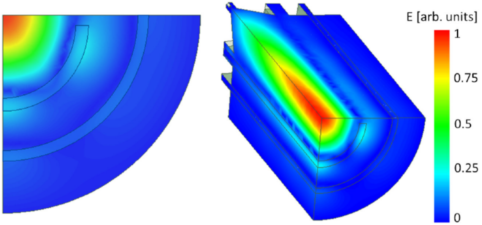






Planned tuning mechanism

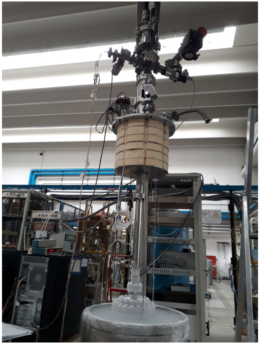




10.1016/j.nima.2020.164641

Δx [mm]	f_{res} [GHz]	Q (10^6)	$C_{030} \times V$ $(10^{-6}$ m$^3)$	$C_{030} \times V \times Q$ (m^3)
0	10.92	2.01	24.75	49.7
0.25	10.81	1.766	26.23	46.3
0.5	10.71	1.80	27.62	49.7
0.75	10.62	1.69	28.94	48.9
1	10.53	1.49	30.00	44.7
1.25	10.45	1.39	31.31	43.5
1.5	10.38	1.39	32.16	44.7

Summary



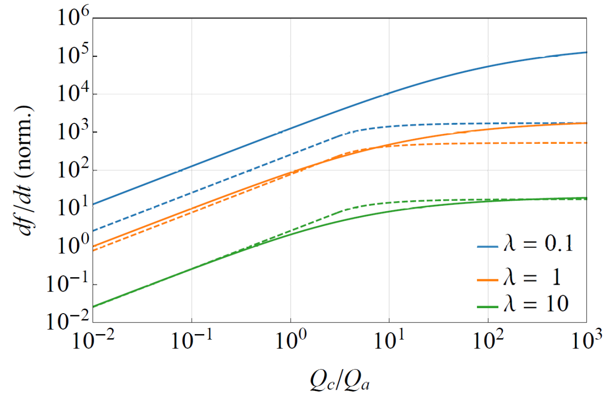
Cavity	V	C_{nml}	$V_{eff} = C \cdot V$	ν_{cav}	Q_0	Reference
Cu	80.6 cm^3	0.69	55.6 cm^3	10.4 GHz	$7.6 \cdot 10^4$ (@8 T)	PRD 99, 101101(R)
Nb-Ti	36.4 cm^3	0.59	21.5 cm^3	9.07 GHz	$4.02 \cdot 10^5$ (@2 T)	PRD 103, 102004
This work	*1056 cm^3*	0.033	*34.7 cm^3*	*10.35 GHz*	$9.2 \cdot 10^6$ (@8 T)	

Thank you for the attention!

Appendix 1 - Haloscope scan rate

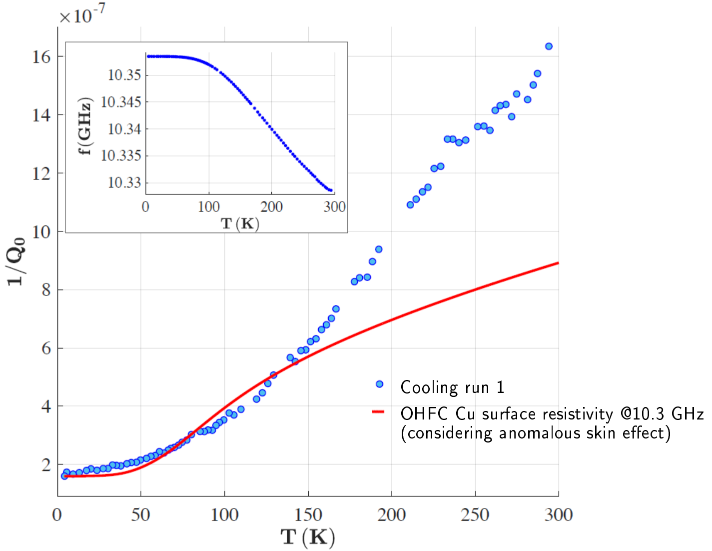
$$\lambda = \frac{T_{added}}{T_{eff}} \quad (T_{sys} = T_{added} + T_{eff}) \; ; \quad P_{axion} = P_0 \frac{\beta}{1+\beta} \frac{Q_L Q_a}{Q_L + Q_a}$$

$$\frac{df}{dt} = \frac{1}{SNR^2} \left(\frac{P_0}{k_B T_{eff}} \right)^2 \left(\frac{\frac{\beta}{1+\beta}}{\frac{4\beta}{(1+\beta)^2+\lambda}} \right)^2 \frac{Q_L Q_a^2}{Q_L + Q_a} \, .$$



Dongok Kim et al JCAP03(2020)066

Appendix 2 - Cavity coolings: losses and frequency vs temperature



Red line postulates that at the 4K point all the losses happen in the copper