Dark matter detection with superconducting qubit in RADES experiment

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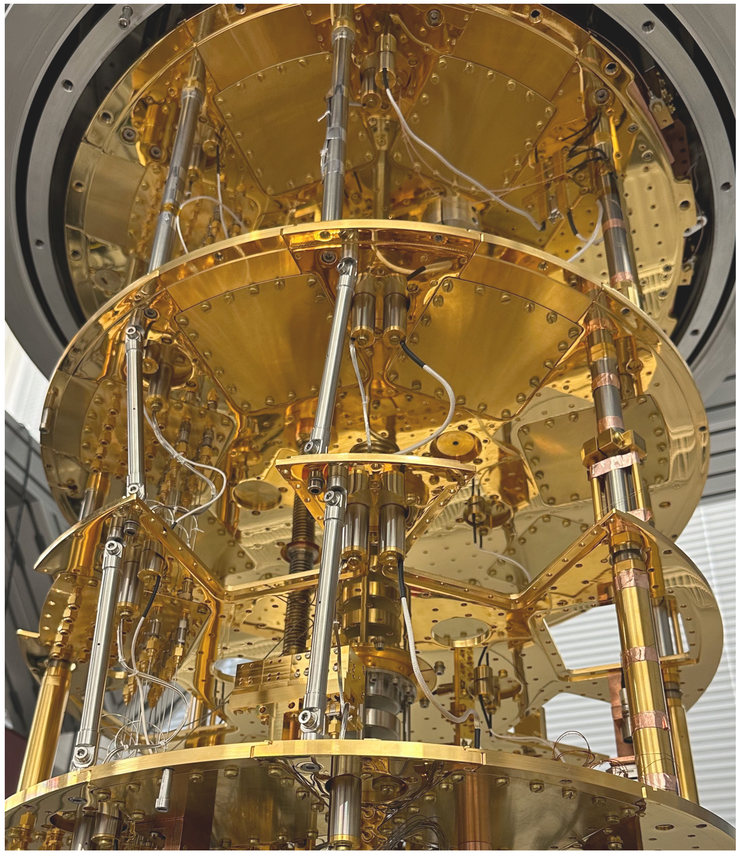
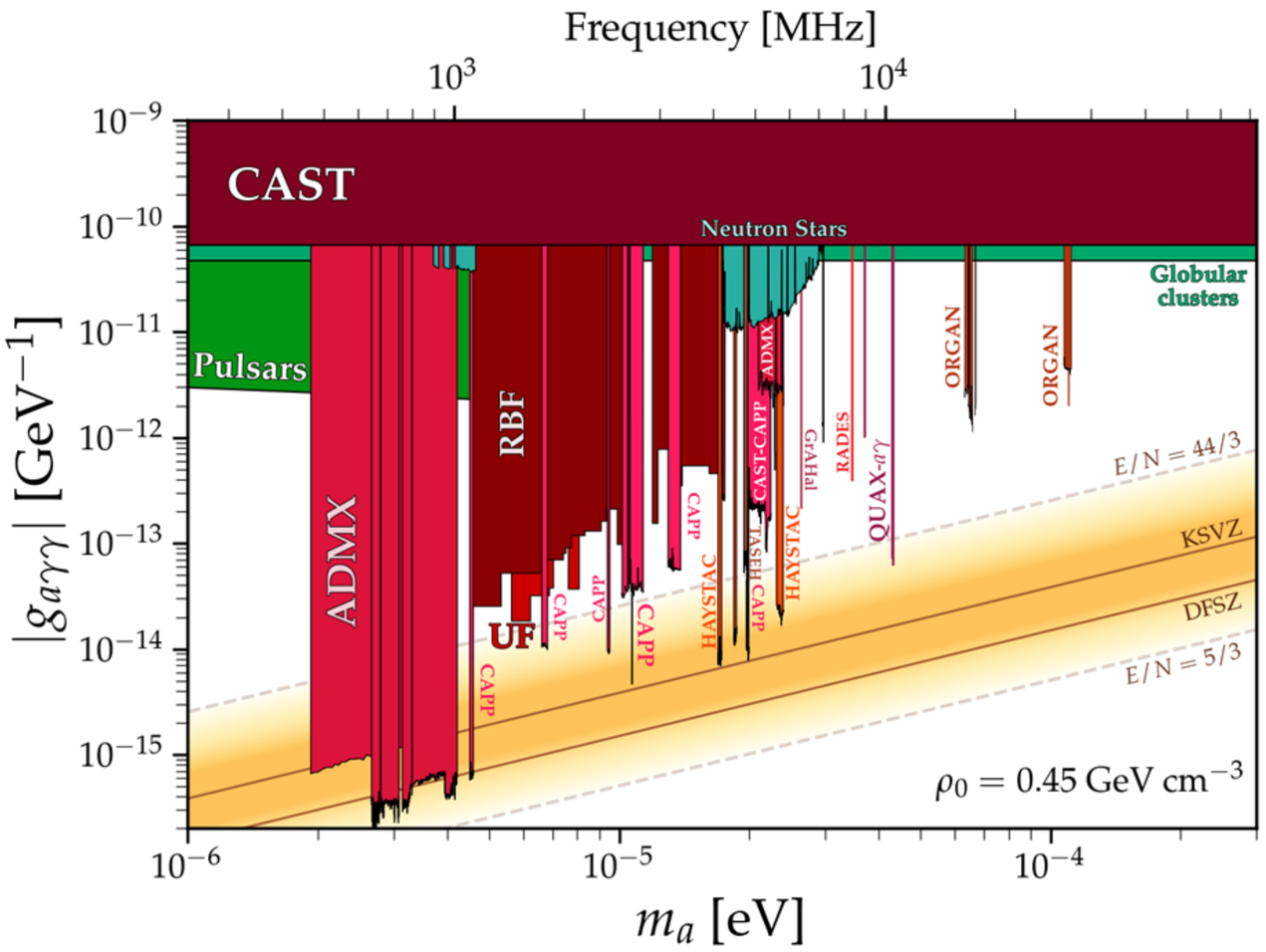
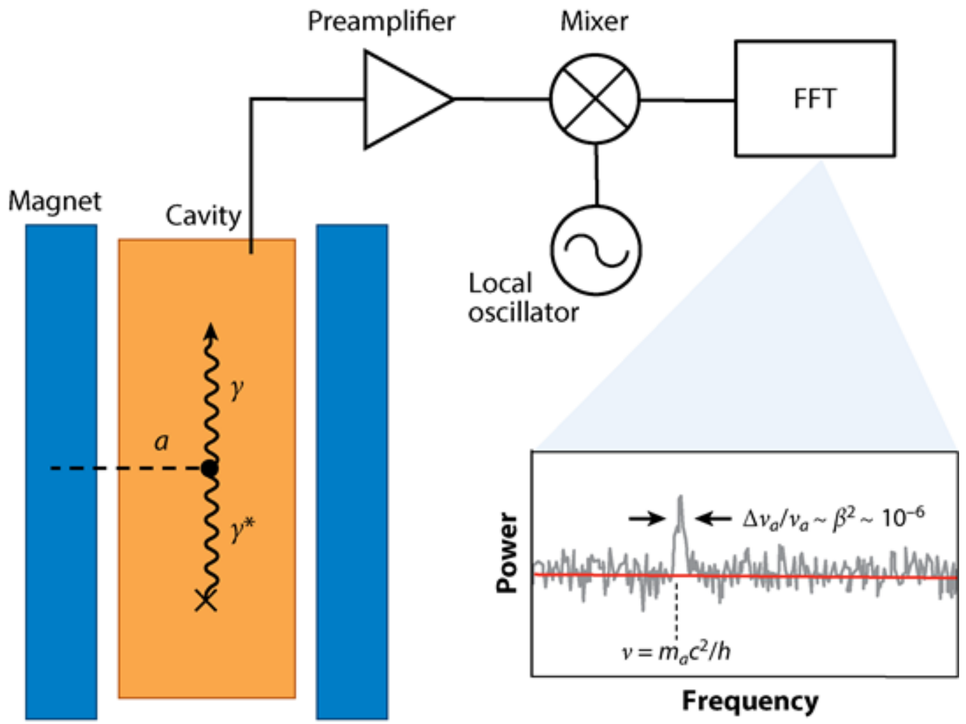


Haloscope

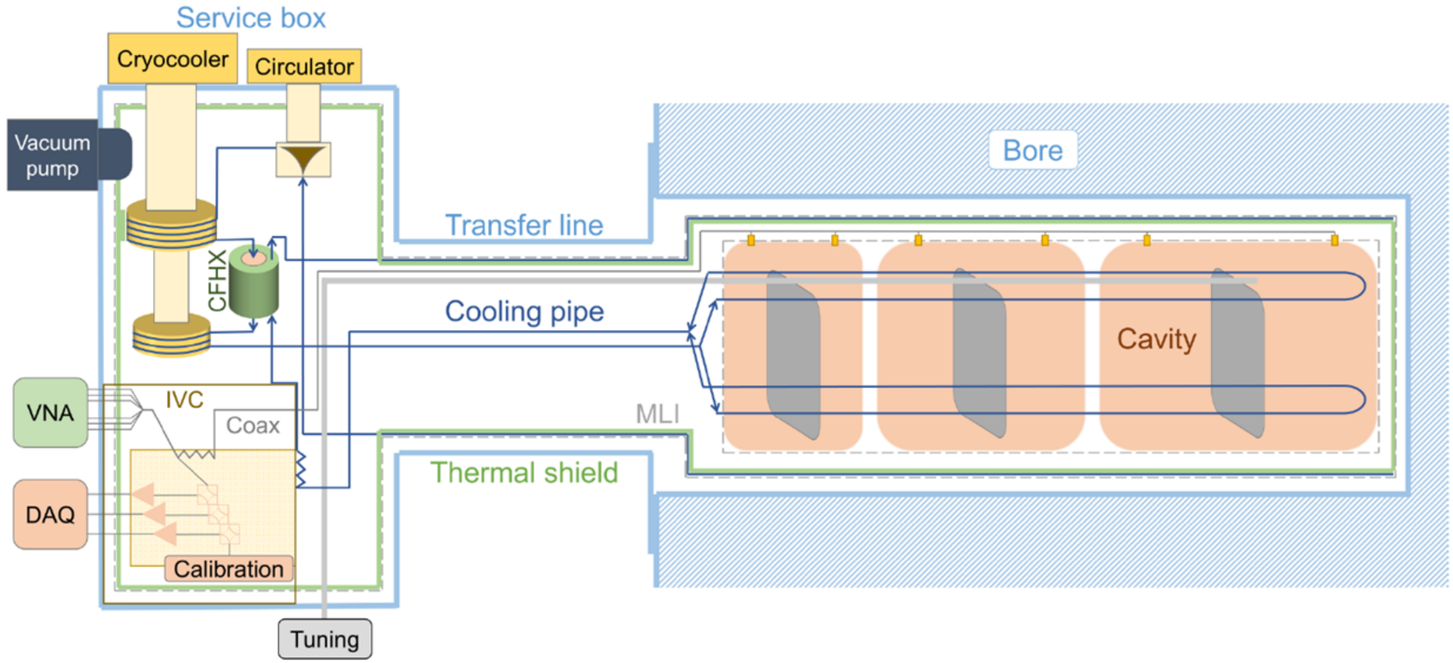


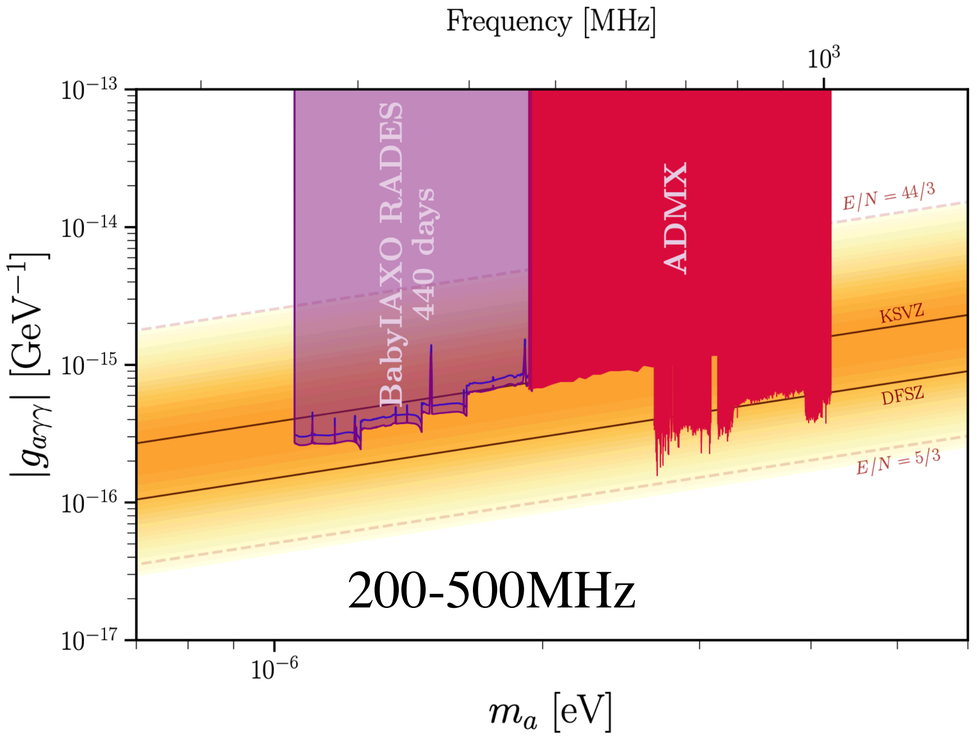


$$P_a = g_{a\gamma\gamma}^2 \rho_{DM} \frac{1}{m_a} B^2 \cdot V \cdot Q_L \cdot C$$

Haloscope at babyIAXO

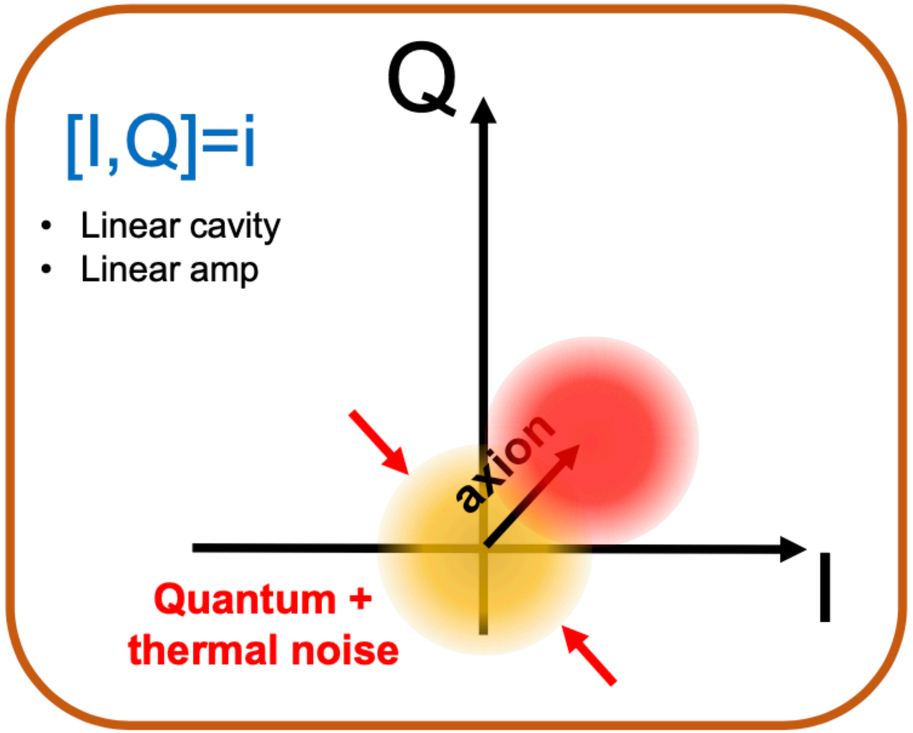
CAST-RADES

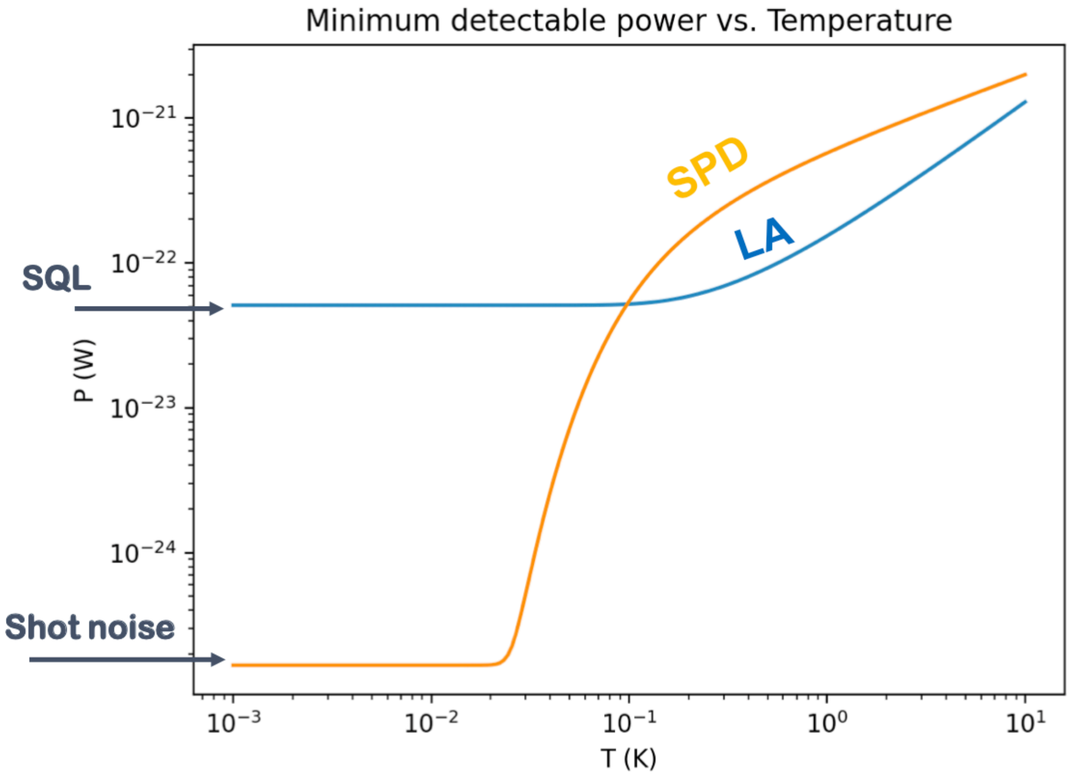




Quantum sensing

From linear amplification (LA) to
counting single photons (SPD)



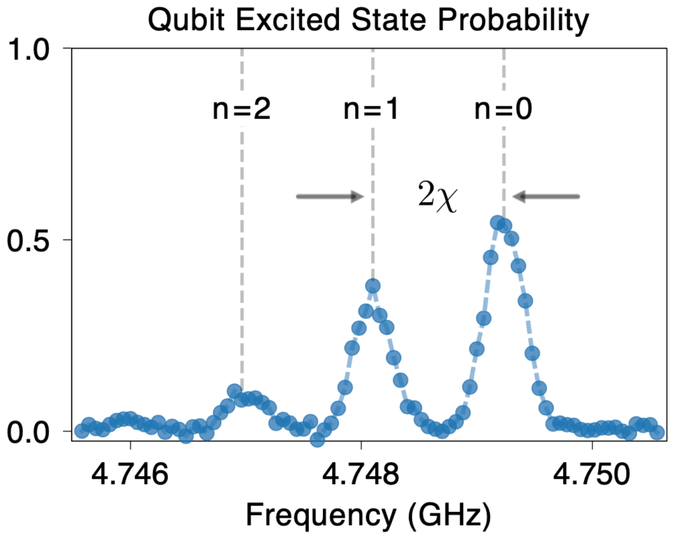


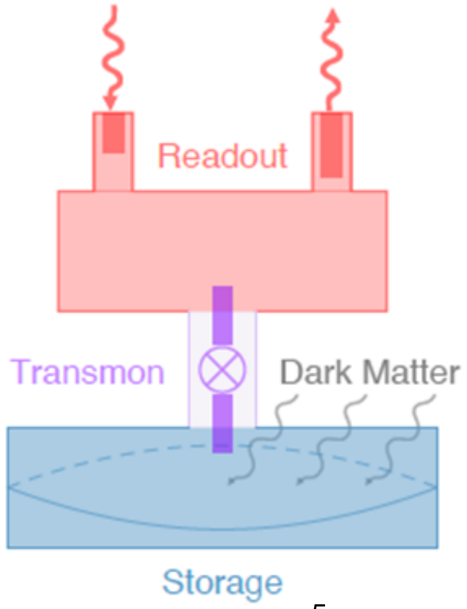
**Single-photon detector (SPD)
vs Linear Amplifier (LA)**

Quantum sensing

$$\mathcal{H} = \omega_c a^\dagger a + \frac{1}{2}\omega_q \sigma_z + 2\chi a^\dagger a \frac{1}{2}\sigma_z$$

Resonator Qubit Interaction

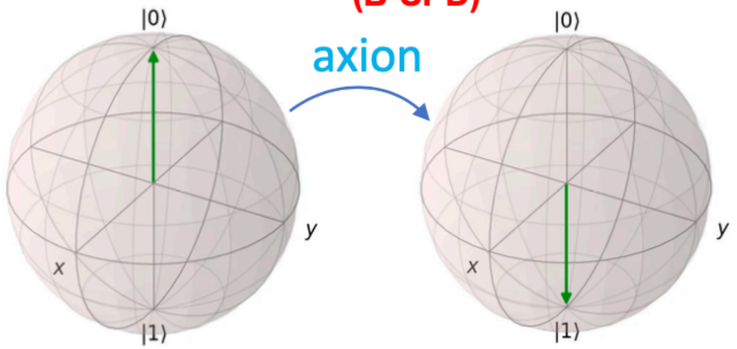




Counting photons

$[N,\phi]=i$

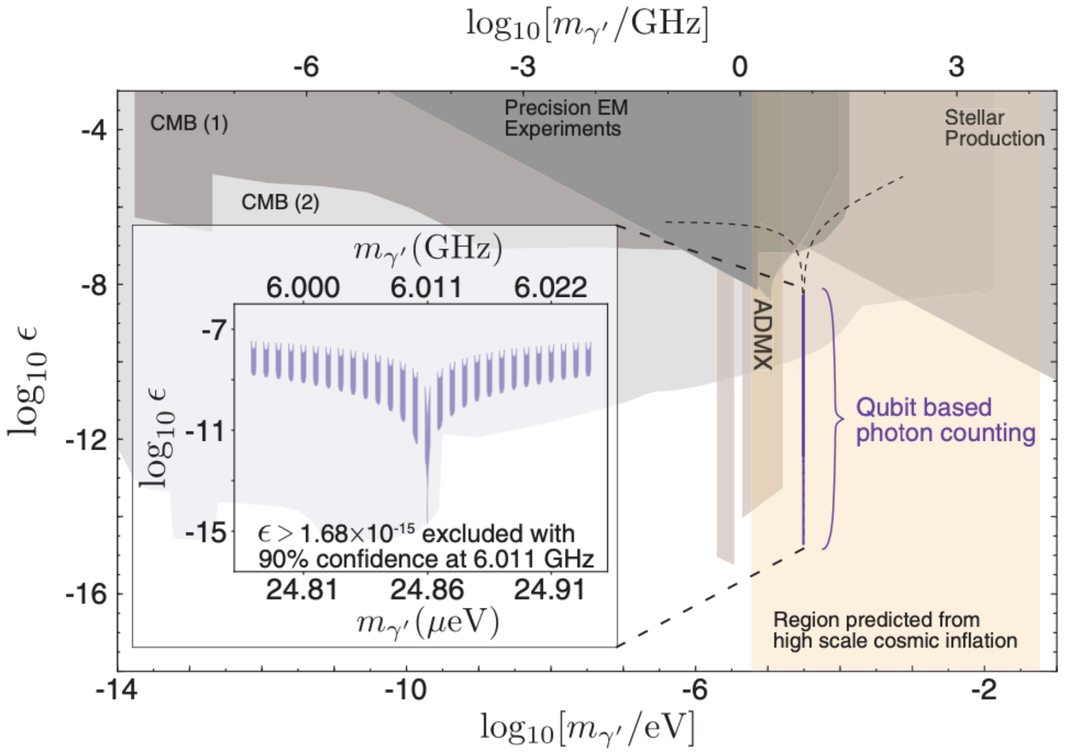
- Linear cavity
- B-resilient Qubit (B-SPD)

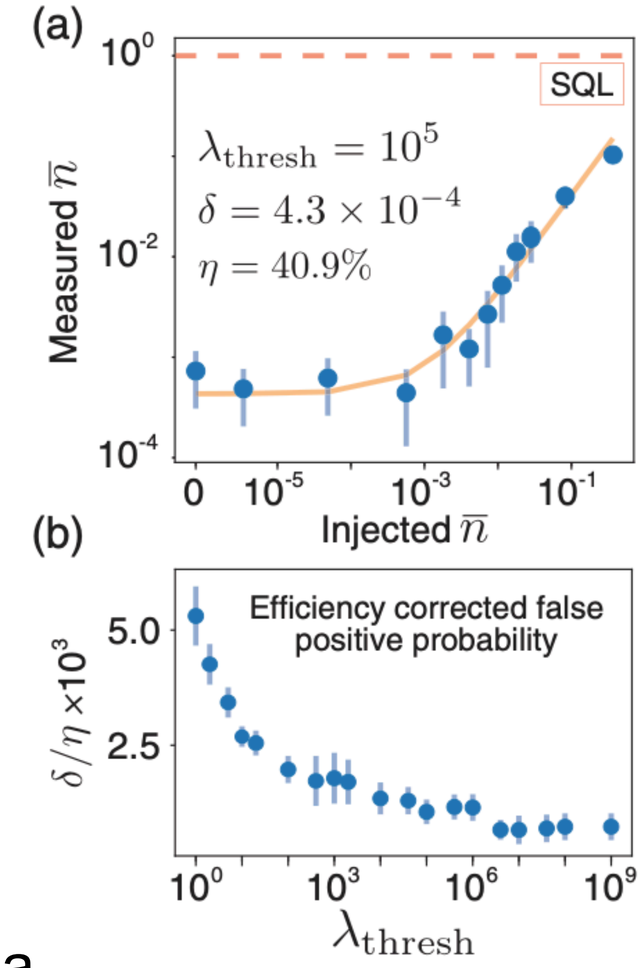


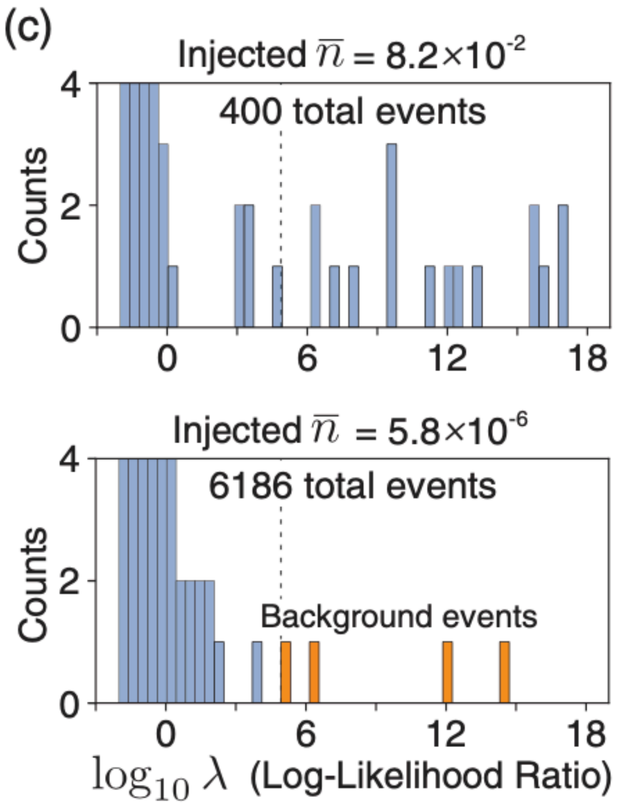
Qubit 0 'No Click'

Qubit 1 'Click'

Quantum sensing

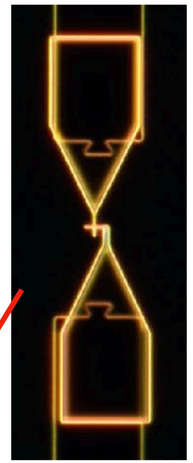


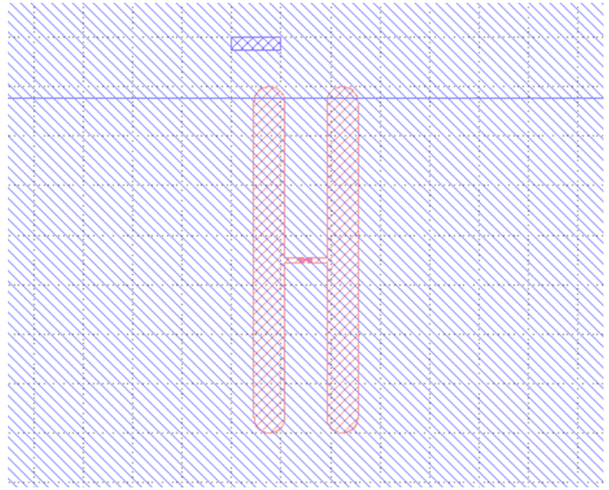


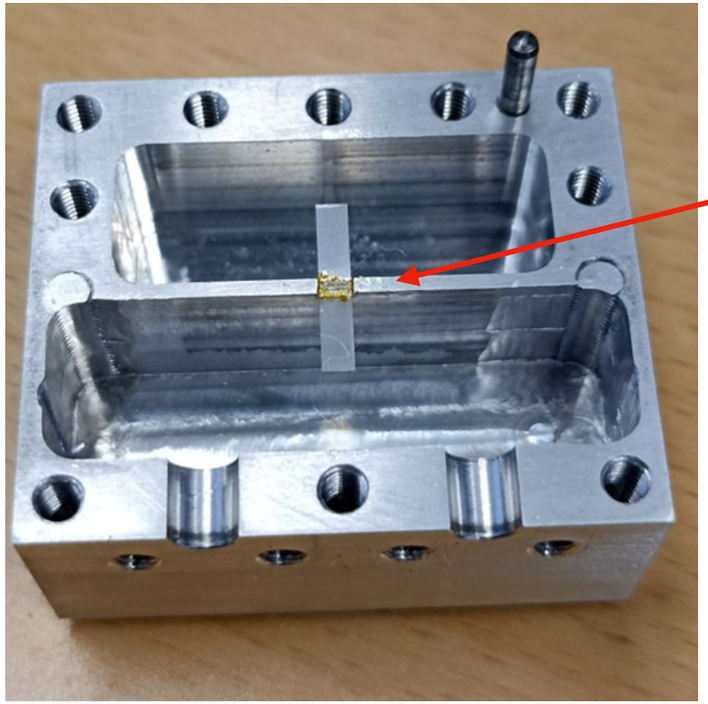


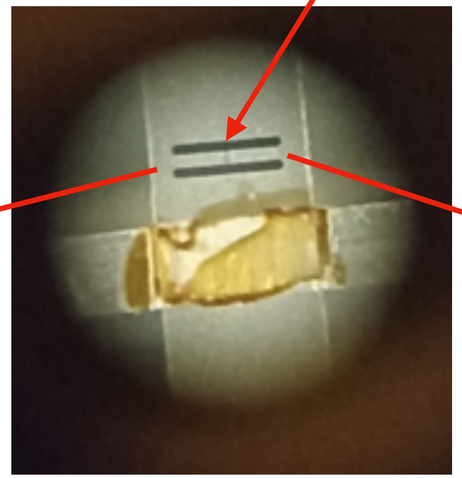
Dixit et al. Searching for dark matter with a superconducting qubit, Phys. Rev. Lett. 126

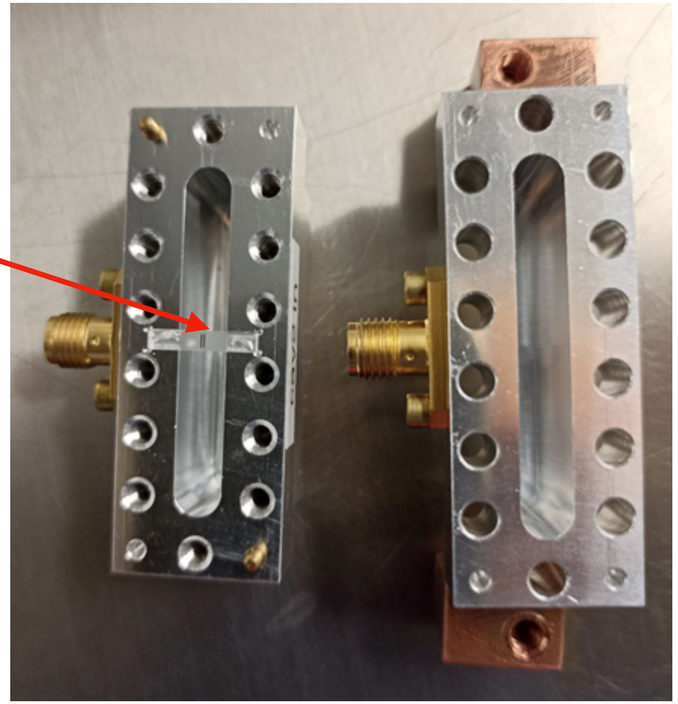
Qubit design and measurements

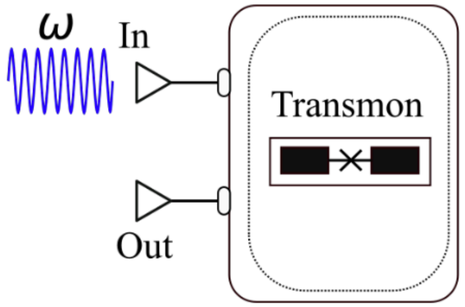


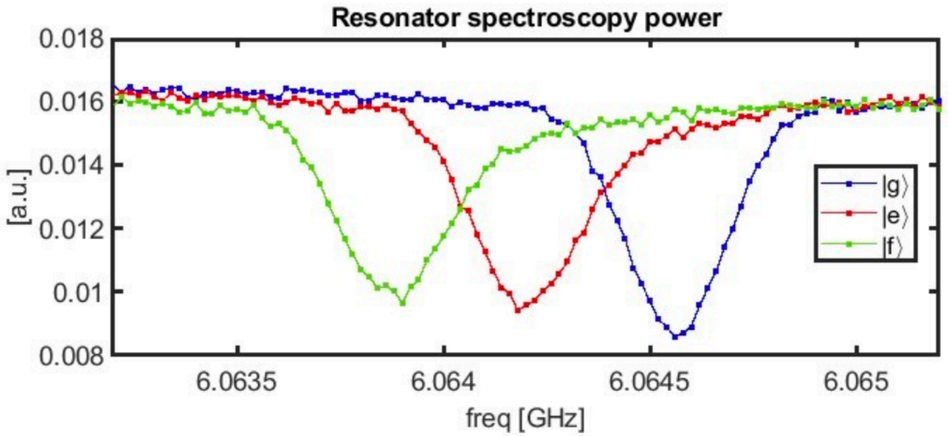


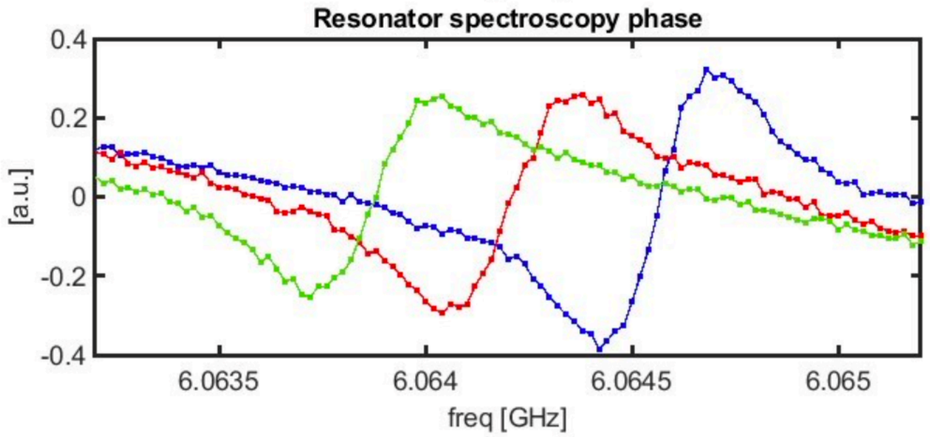




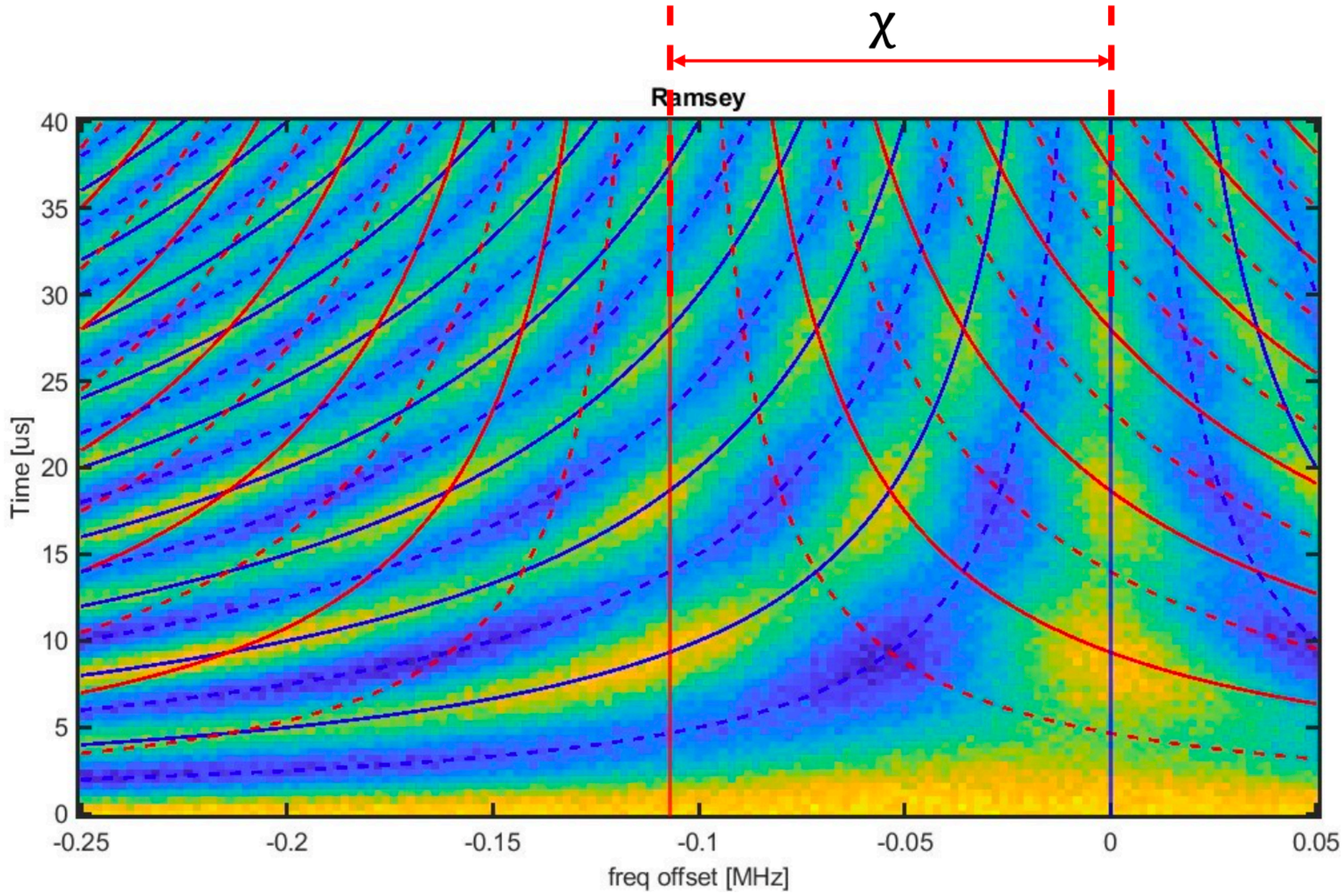


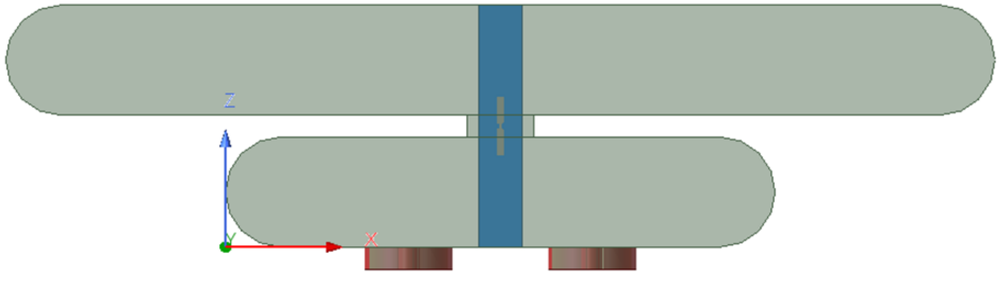




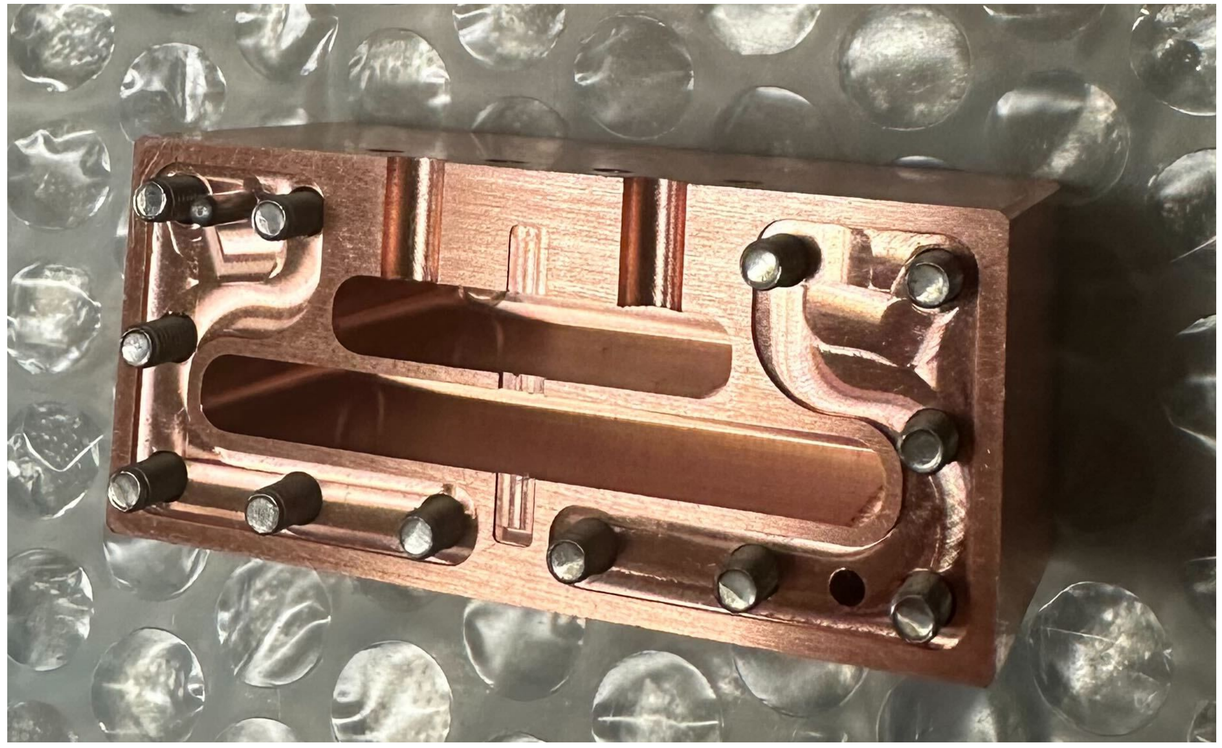


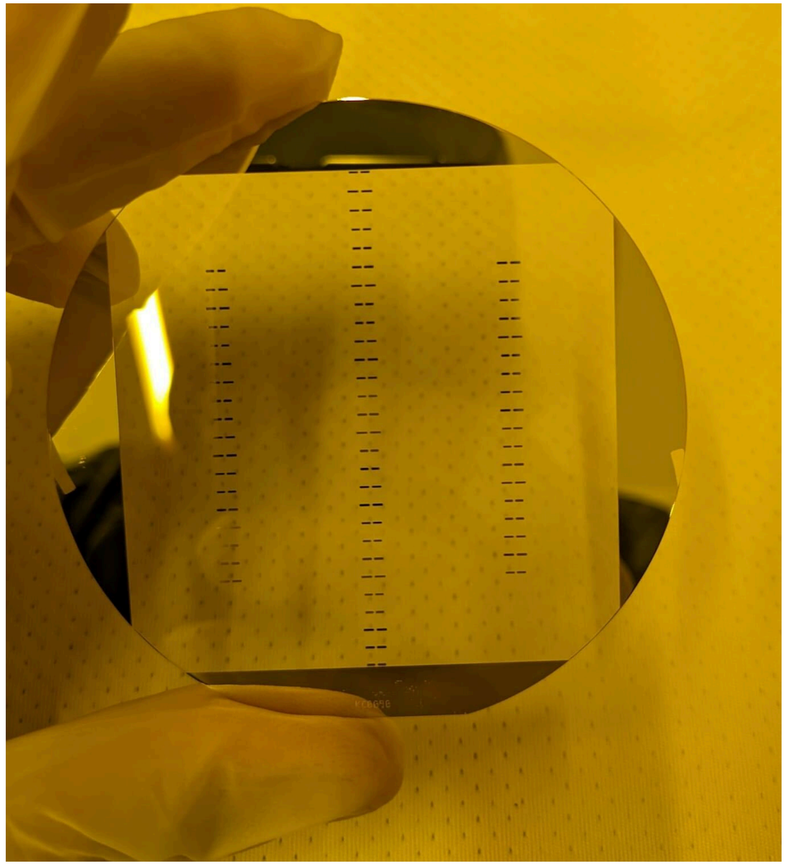
Ramsey chevrons (thermal photons in the cavity)





Storage cavity: ~ 5 GHz
Readout cavity: ~ 7 GHz





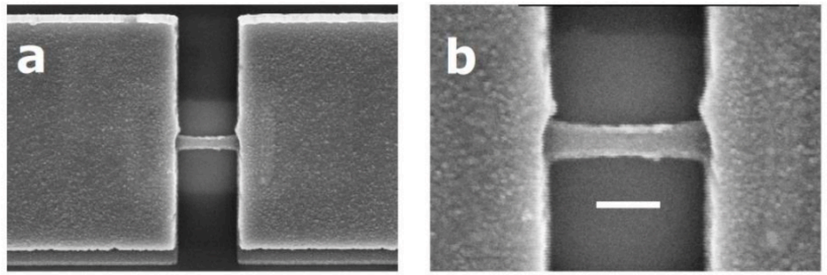
Transmons fabricated from NIST

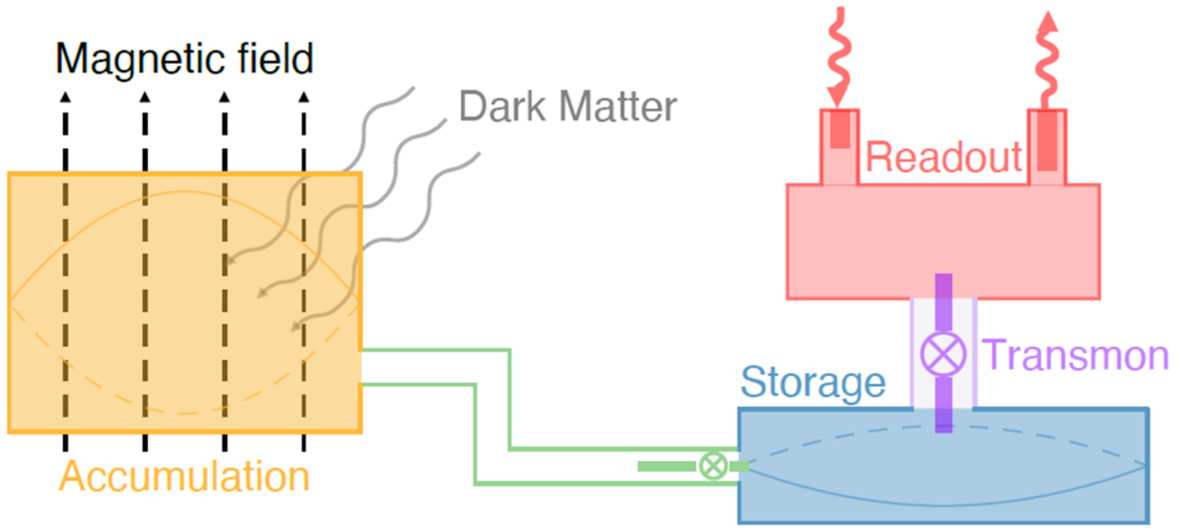
Installation and testing on the way…

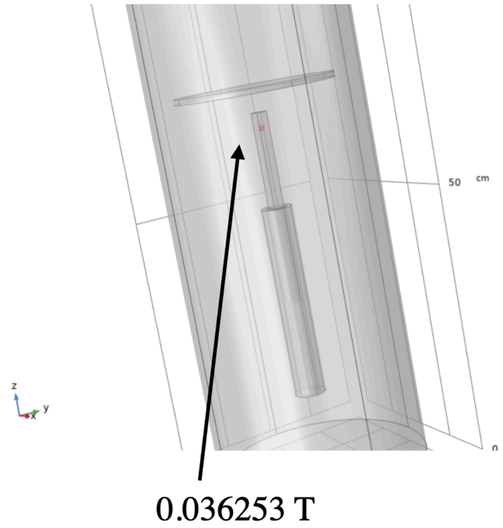
For axion detection

With magnetic field

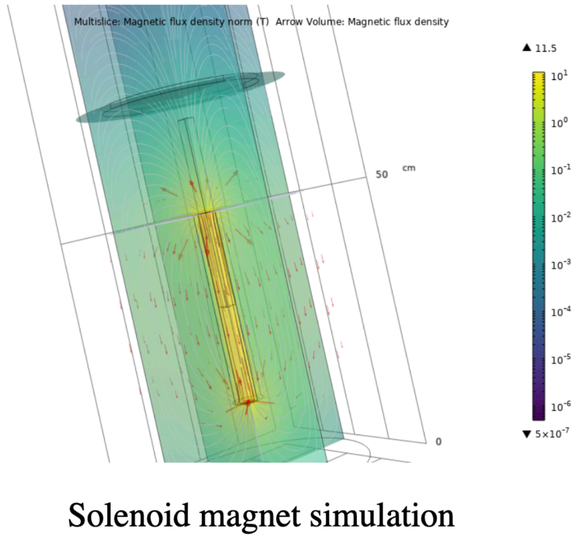
- Magnetic field resilient superconducting quantum circuits with granular aluminium, A. Théry et al. submitted to PRL‘23 (PI2)







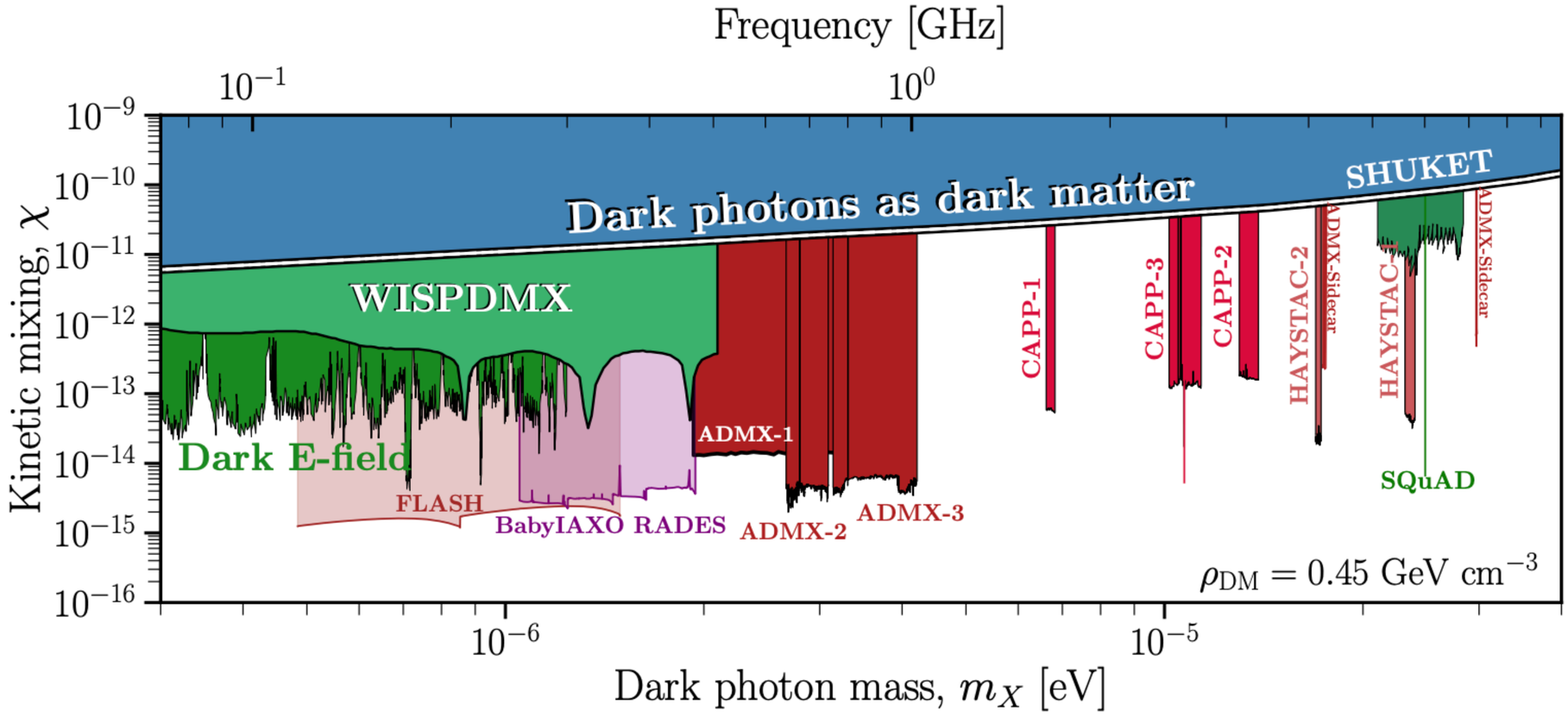
0.036253 T



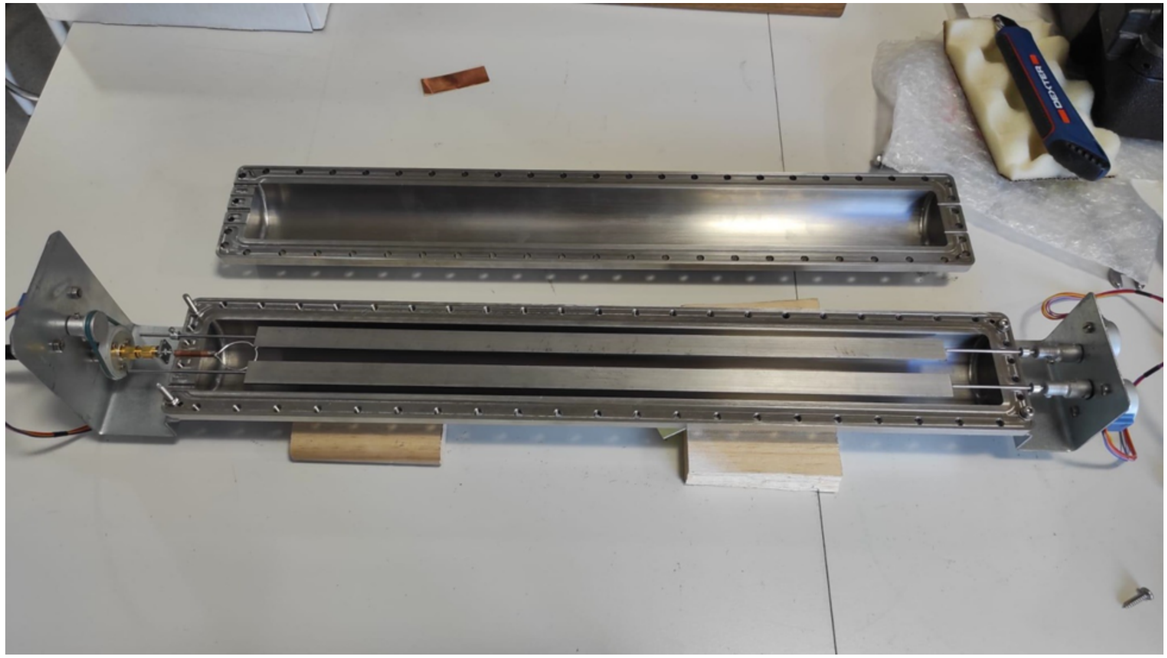
Solenoid magnet simulation

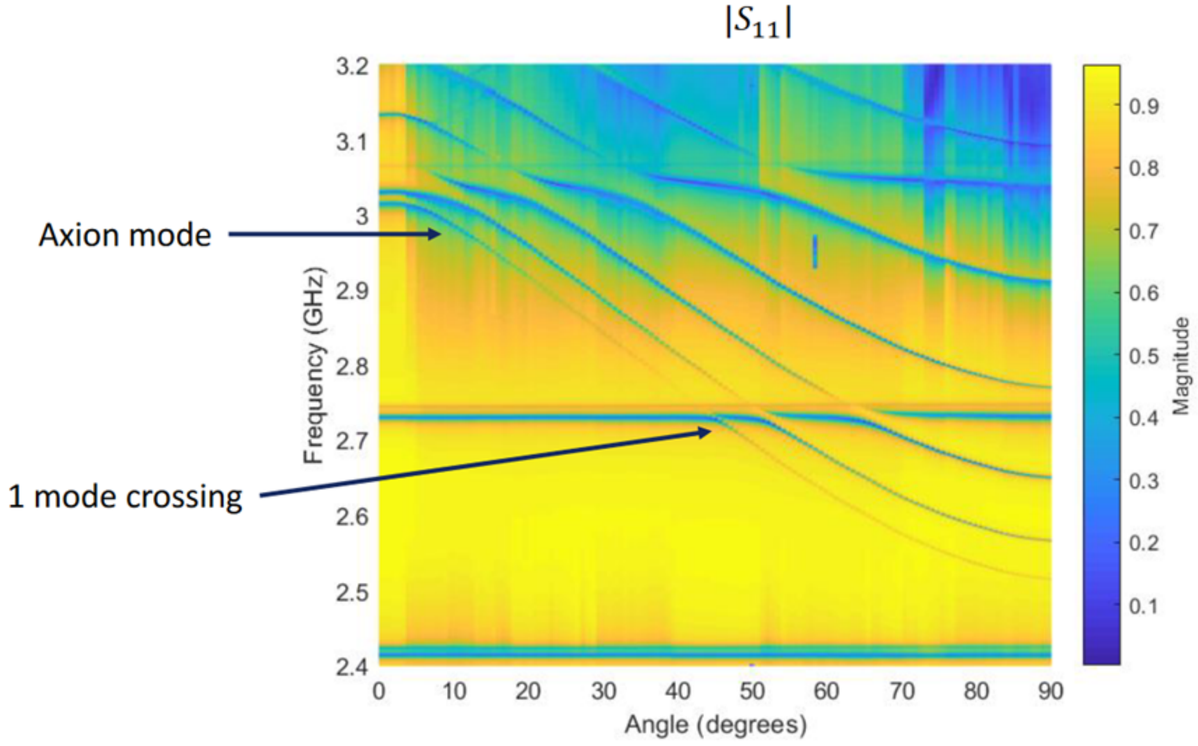
Backup

Haloscope

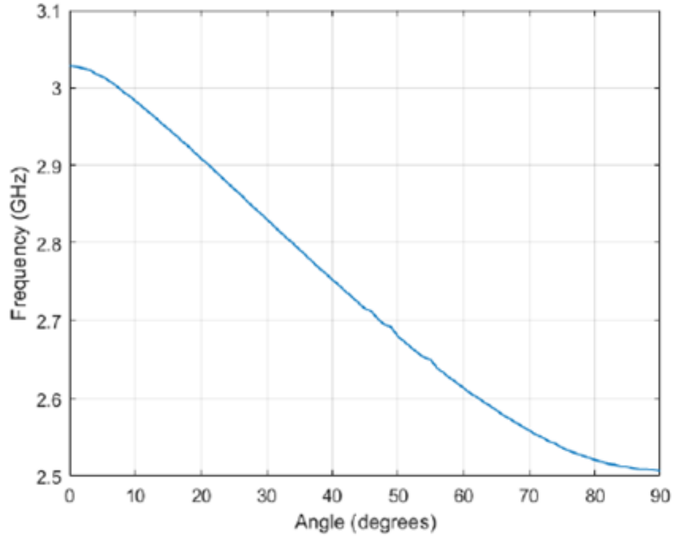

Frequency [GHz]
10^{-1}
10^{0}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
Kinetic mixing, χ
Dark photons as dark matter
SHUKET
WISPDMX
Dark E-field
FLASH
BabyIAXO
RADES
ADMX-1
ADMX-2
ADMX-3
CAPP-1
CAPP-3
CAPP-2
HAYSTAC-2
ADMX-Sidecar
HAYSTAC
ADMX-Sidecar
SQuAD
$\rho_{\rm DM} = 0.45$ GeV cm^{-3}
10^{-6}
10^{-5}
Dark photon mass, m_X [eV]

Haloscope



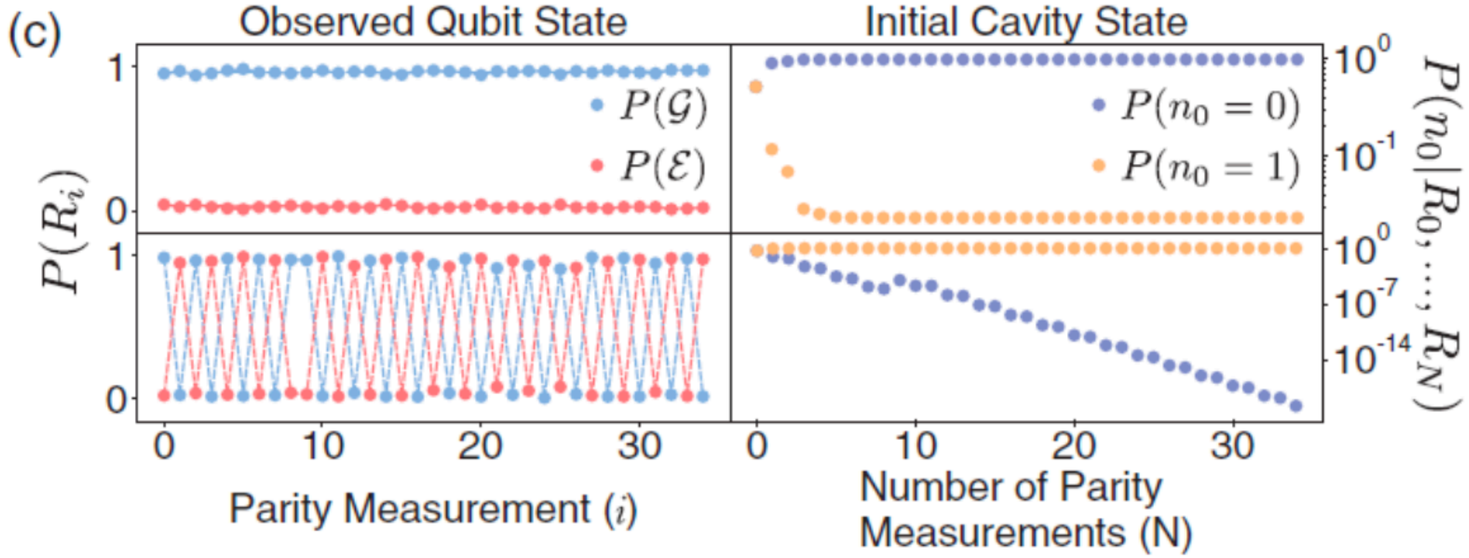


Measurements every 0.7°



Simulation

Independent measurement with 30 parity measurements



In total 15141 independent measurements.
846 us each measurement.
→ 12,81s with 65% duty cycle = 8,33 s

Q4

```
Qubit Freq = 4.574 GHz
E_J = 13.398 GHz
E_C: 189.946 MHz
E_J/E_C: 70.538
Charge Dispersion T2: 3109.193 us
Qubit Anharmonicity = 219.42 MHz
2XChi storage = 5.899 MHz
g storage = 31.132 MHz
storage Freq = 4.974 GHz
storage Delta = 0.4 GHz
2XChi readout = 0.911 MHz
g readout = 103.189 MHz
Readout Freq = 6.951 GHz
Readout Delta = 2.377 GHz
Readout Linewidth = 0.232 MHz
Purcell T1 estimate = 364.469 us
```

Qubit antenna length 1.0mm,*0.3mm for both, gap0.24mm

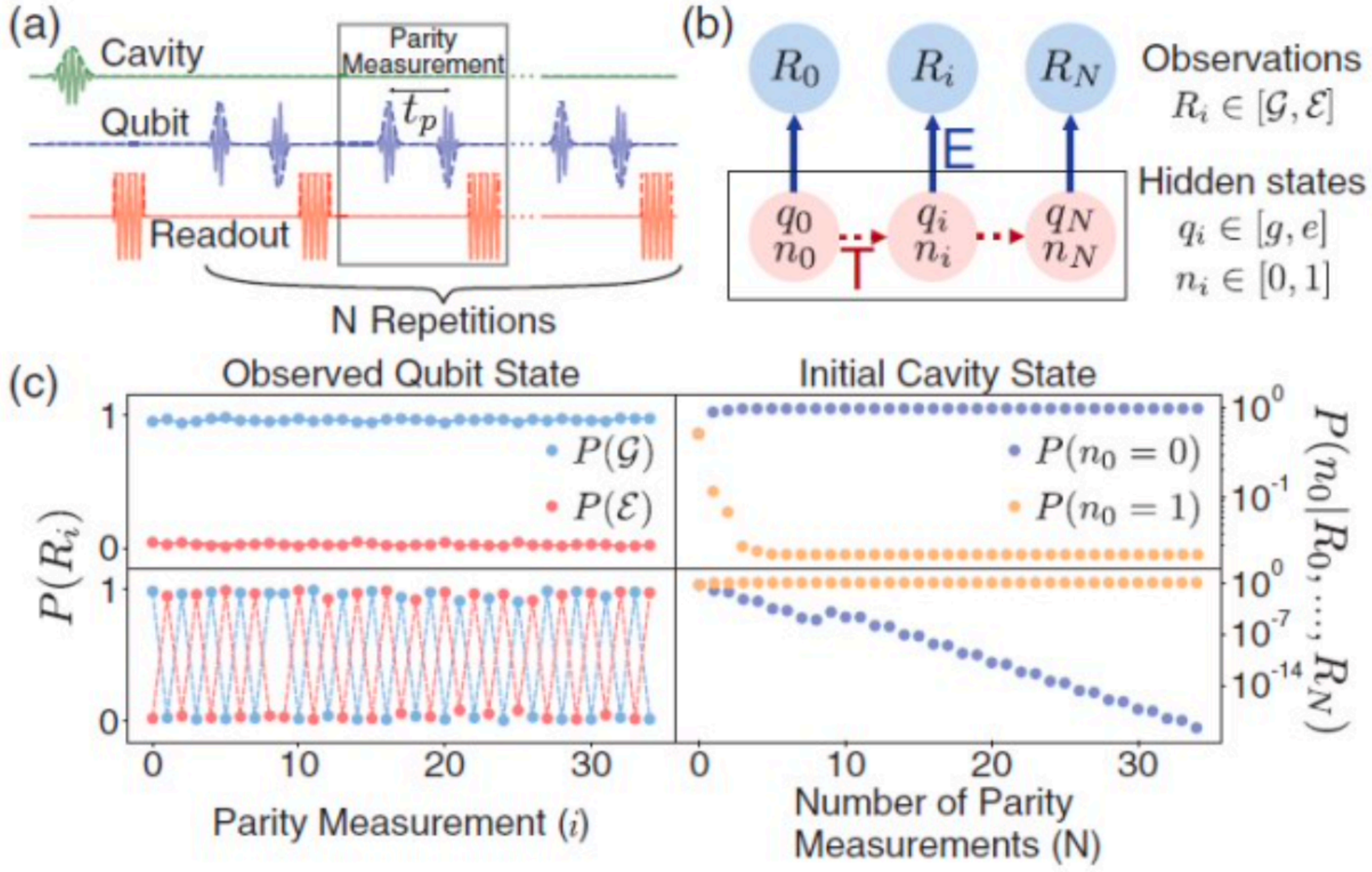
12.2nH 3.5fF

Q1

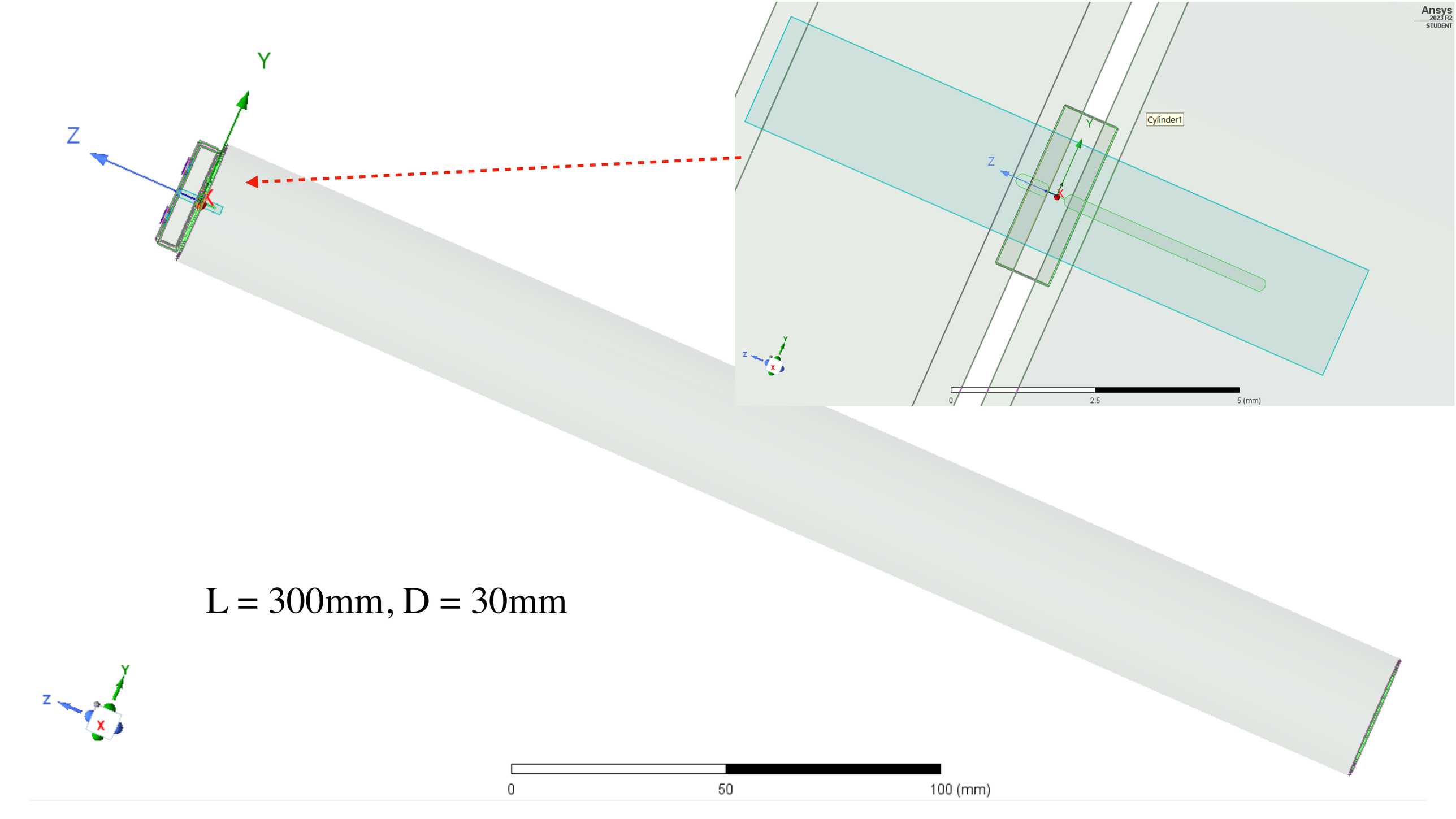
```
Qubit Freq = 4.486 GHz
E_J = 12.574 GHz
E_C: 202.675 MHz
E_J/E_C: 62.04
Charge Dispersion T2: 781.188 us
Qubit Anharmonicity = 227.207 MHz
2XChi storage = 4.85 MHz
g storage = 36.707 MHz
storage Freq = 4.973 GHz
storage Delta = 0.487 GHz
2XChi readout = 0.924 MHz
g readout = 105.875 MHz
Readout Freq = 6.951 GHz
Readout Delta = 2.465 GHz
Readout Linewidth = 0.232 MHz
Purcell T1 estimate = 372.238 us
```

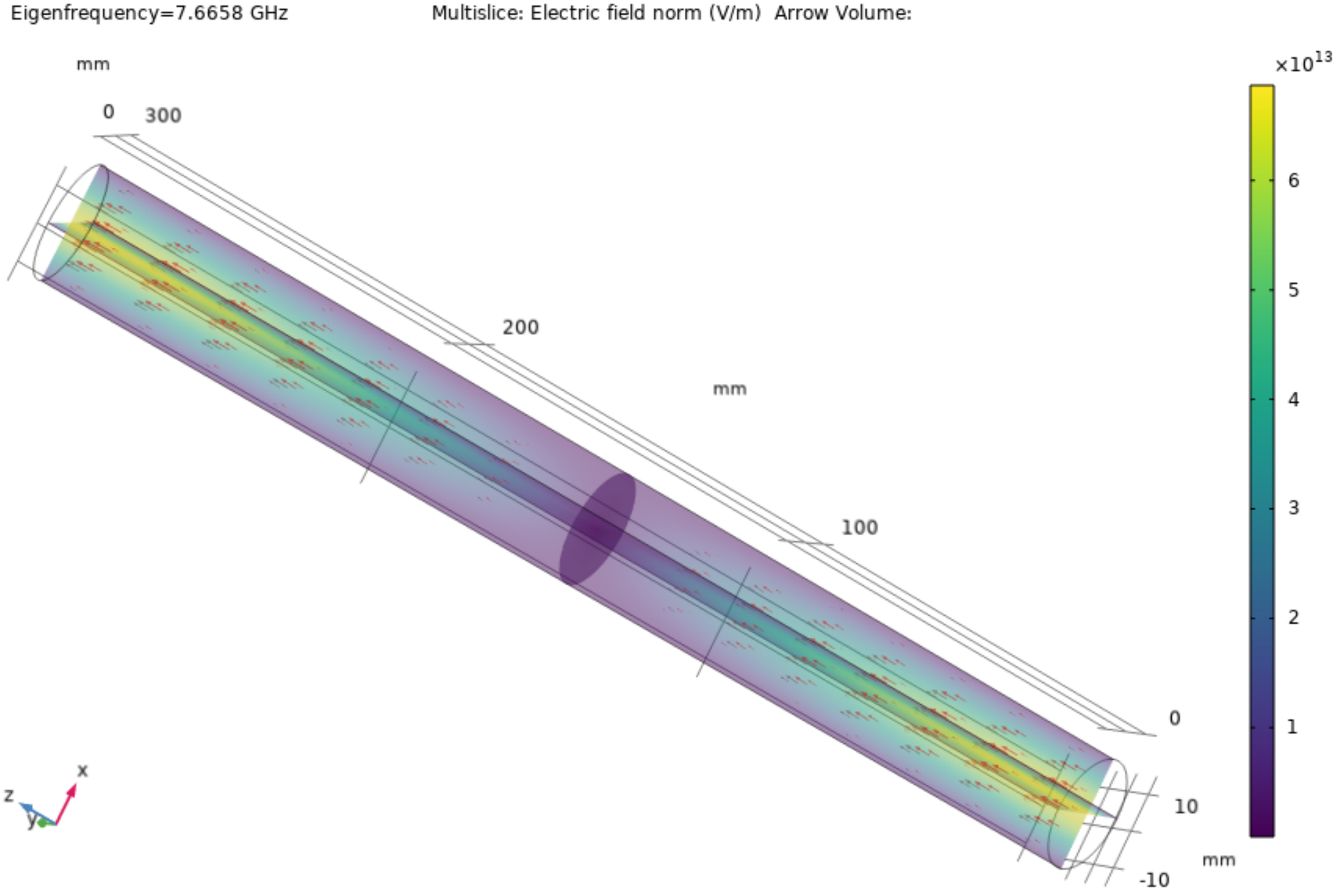
Qubit antenna length 1.0mm,*0.3mm for both, gap0.3mm

13nH 3.5fF

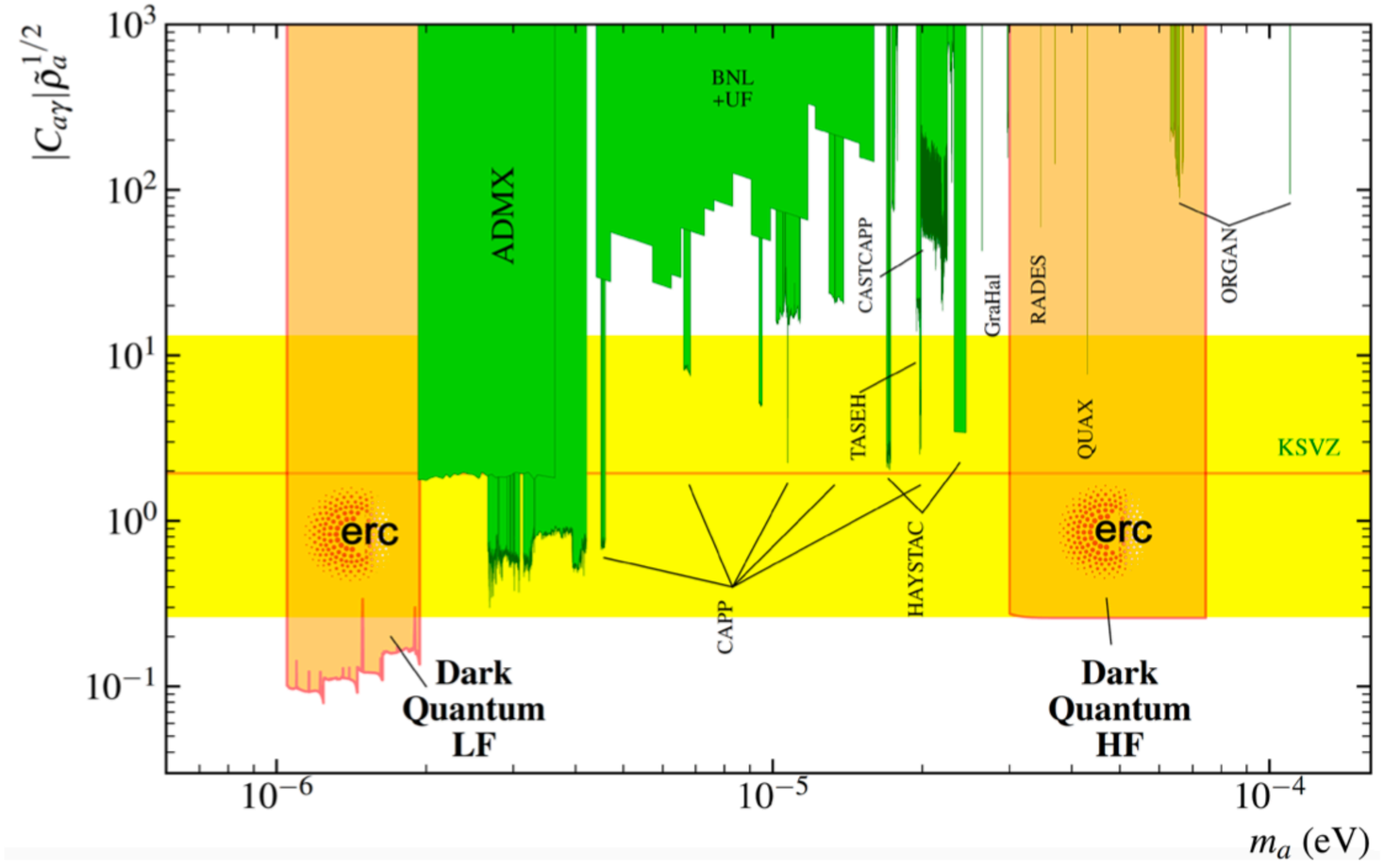


*Akash V. Dixit, et.al., Phys. Rev. Lett. **126**, 141302 (2021)


Ansys
2023 R2
STUDENT
Cylinder1
Y
Z
X
0
2.5
5 (mm)
L = 300mm, D = 30mm
0
50
100 (mm)


Eigenfrequency=7.6658 GHz
Multislice: Electric field norm (V/m)
Arrow Volume:
mm
0
300
200
mm
100
0
10
-10
mm
×10^13
6
5
4
3
2
1
x
z
y

ERC DarkQuantum



200-500 MHz **8-18 GHz**