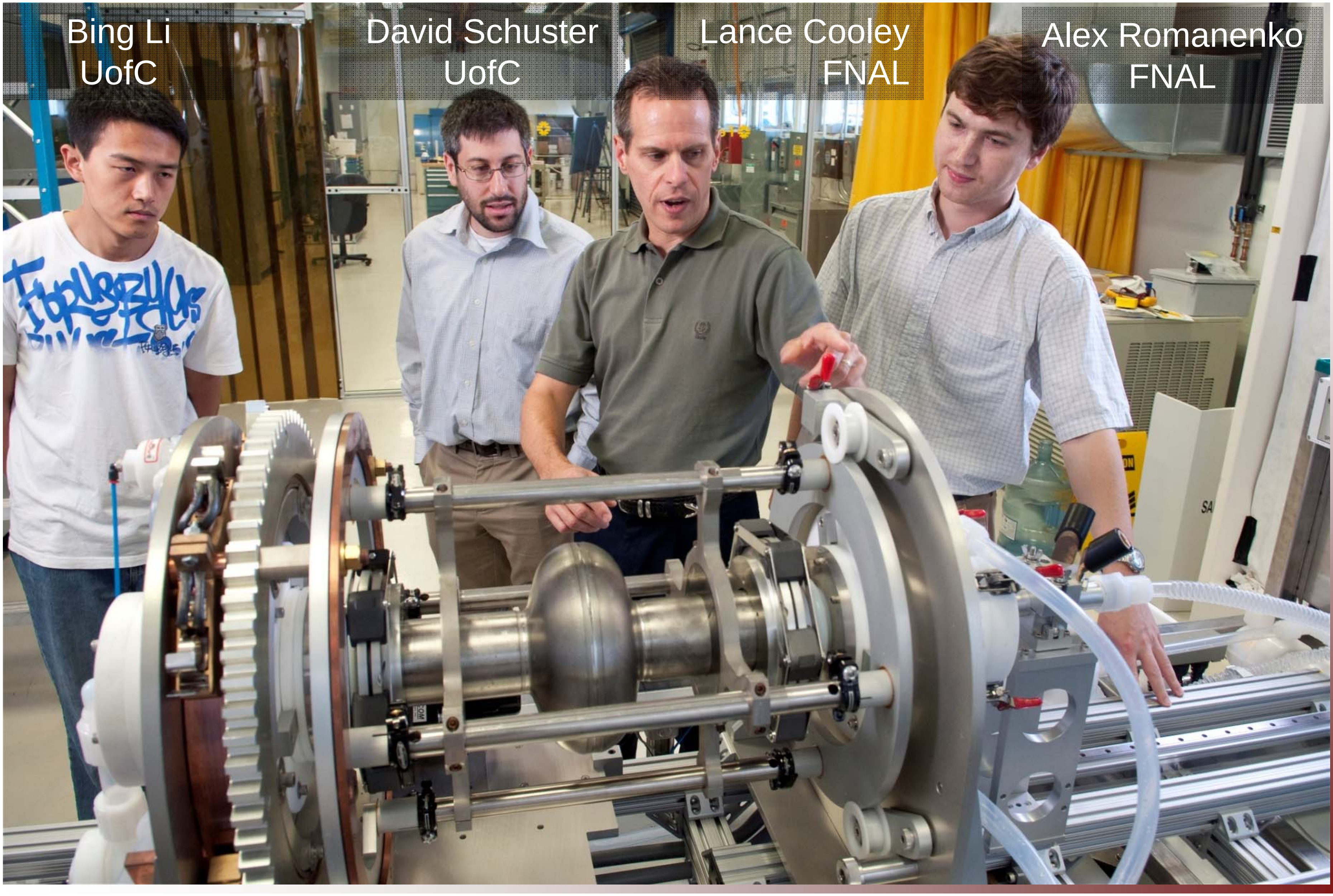
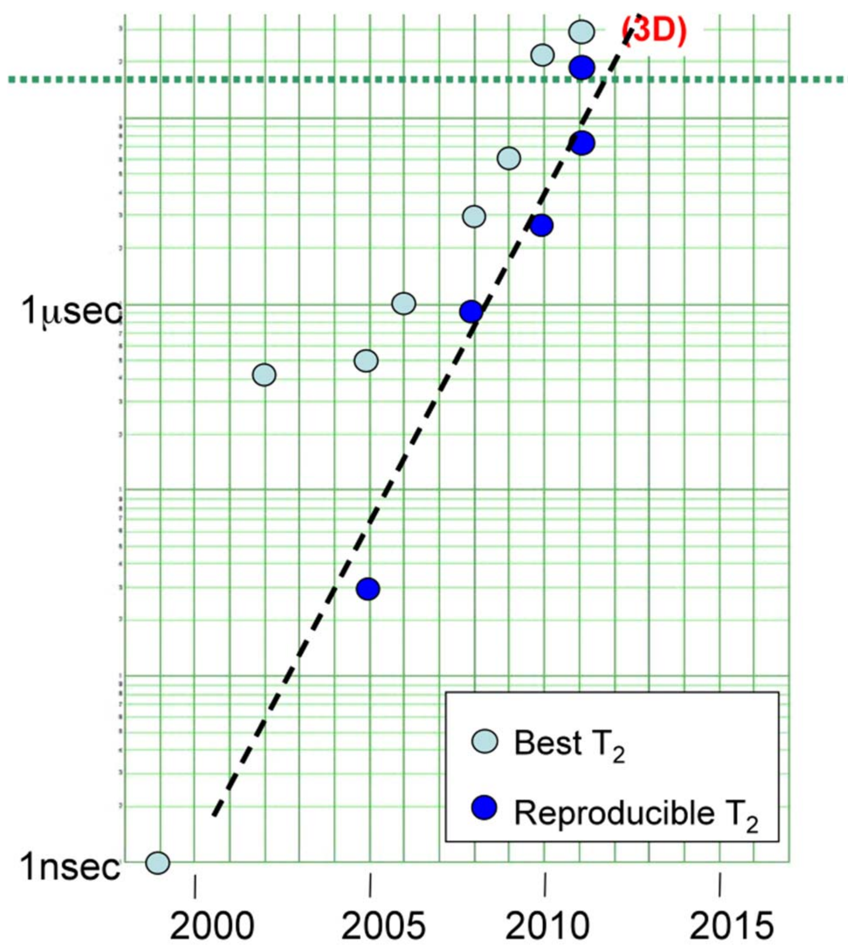
Understanding Ultrahigh Quality Factor Accelerator Cavities in the Quantum Regime



State of the art for SC qubits



From this week's

APS Physics Viewpoint /PRL:

- Best T_2 ~ 50 µsec
- Q_2 ~ 400,000

Why are we excited?

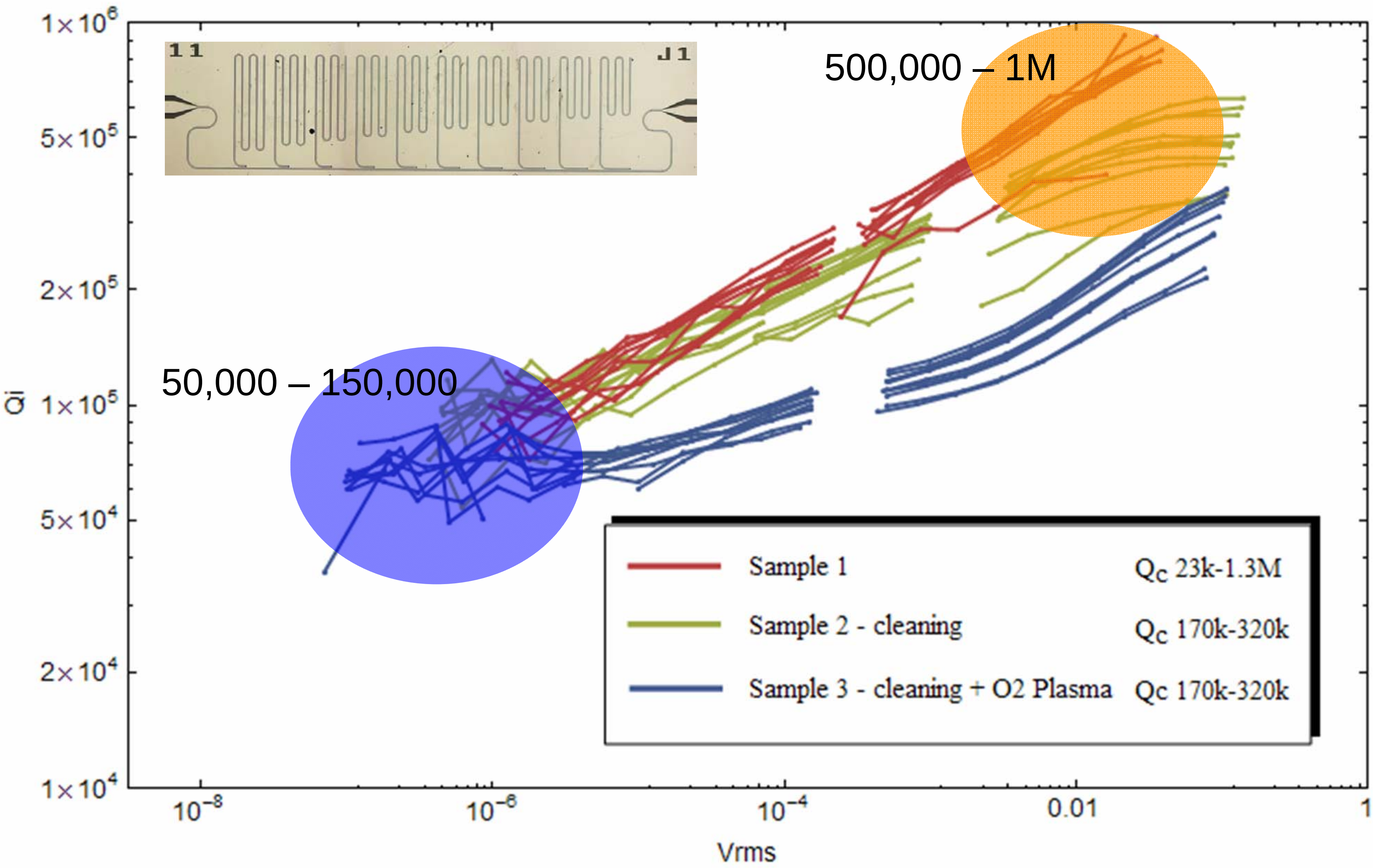
- A typical accelerator cavity has $Q > 10^{10}$
- This corresponds to $T_2 > 1$ second!

Fermilab

H. Paik, D. I. Schuster, et. al. PRL 107, 240501 (2011)

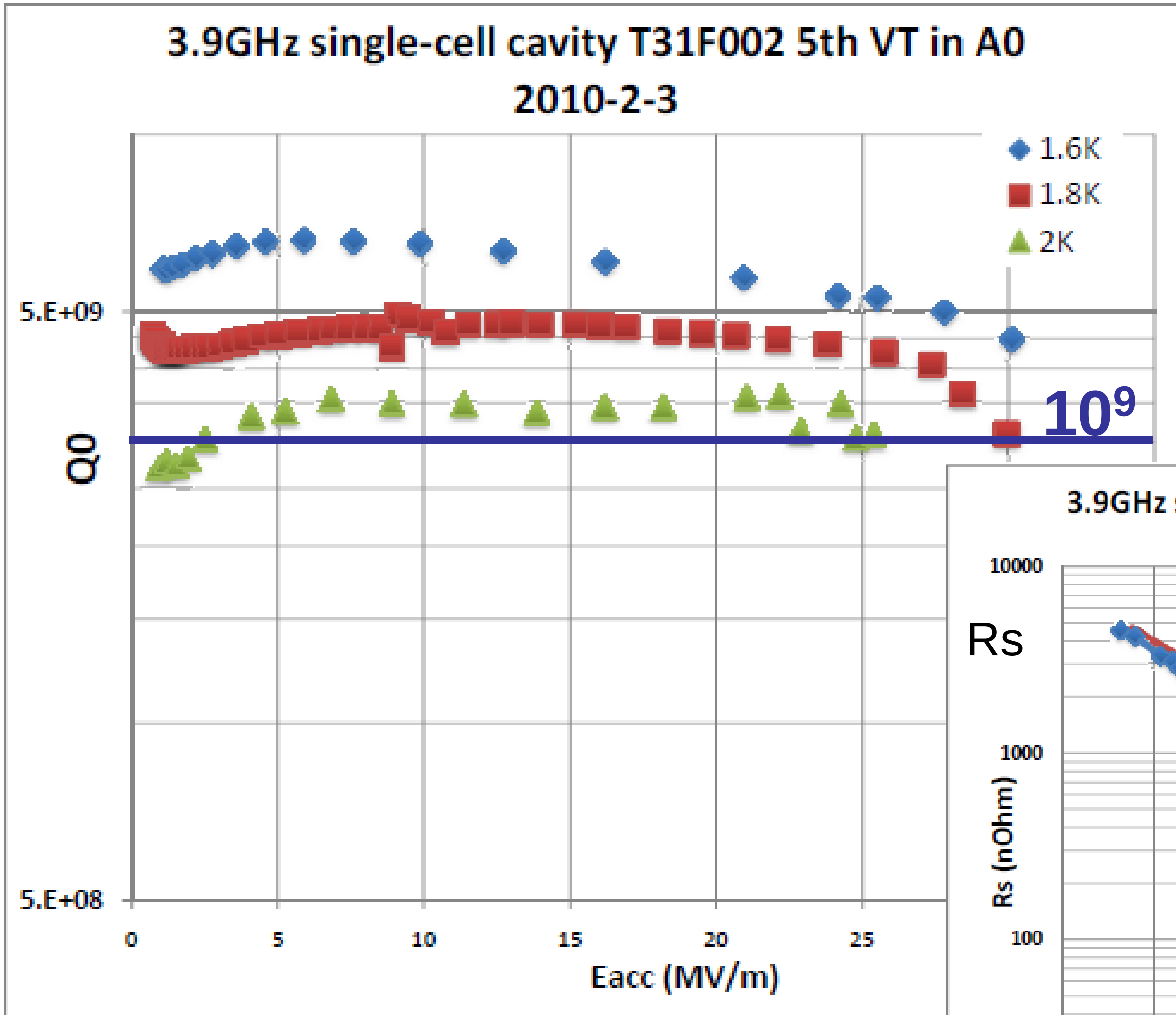
First results (power dependence)

Resonator Internal Quality

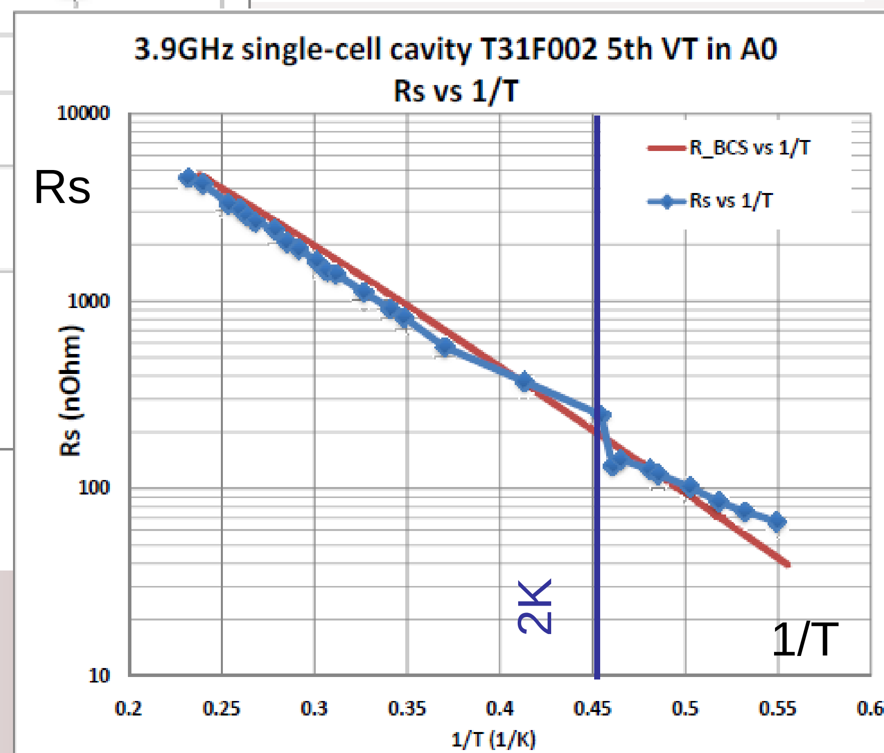


Fermilab

Typical Fermilab cavity performance



- Q_0 is limited to 10^9 by excitation of normal electrons at 2 K
- We expect residual resistance of ~10 nΩ based on known results for this process



Fermilab

Quantum Computer vs. Accelerator Cavities

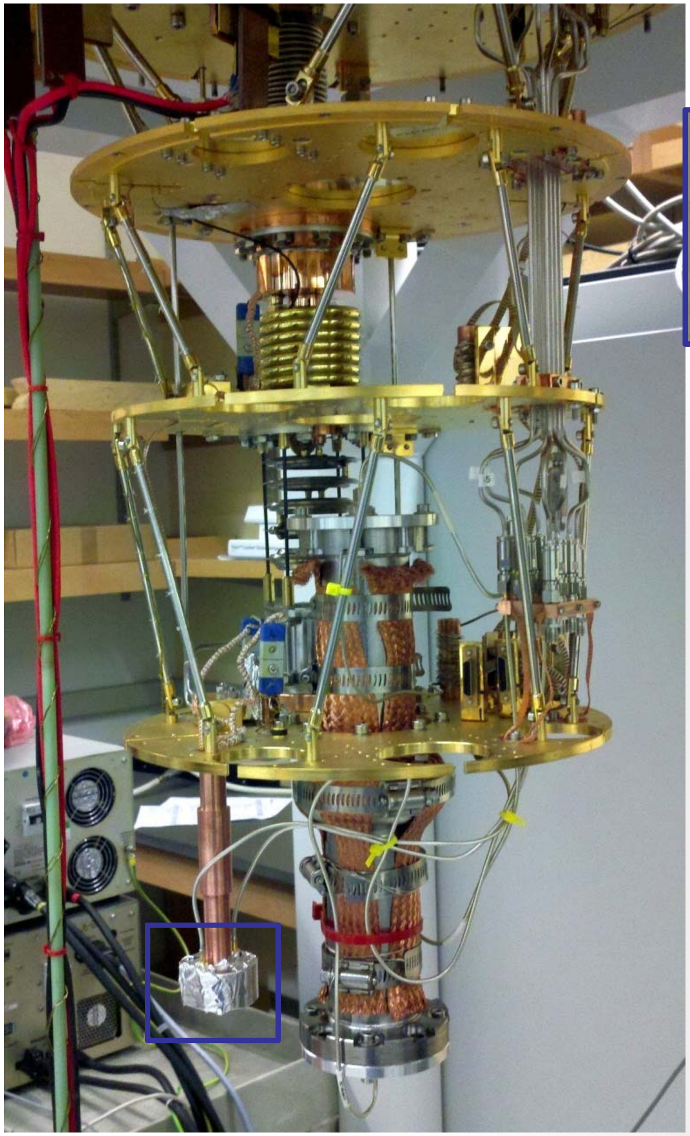
- QC cavities optimized for **coupling to single photon**, limited by **loss of single photon**
- Accelerator cavities optimized for **highest accelerating field**, limited by **breakdown at maximum power**
- Both want **high Q** but everything else is different

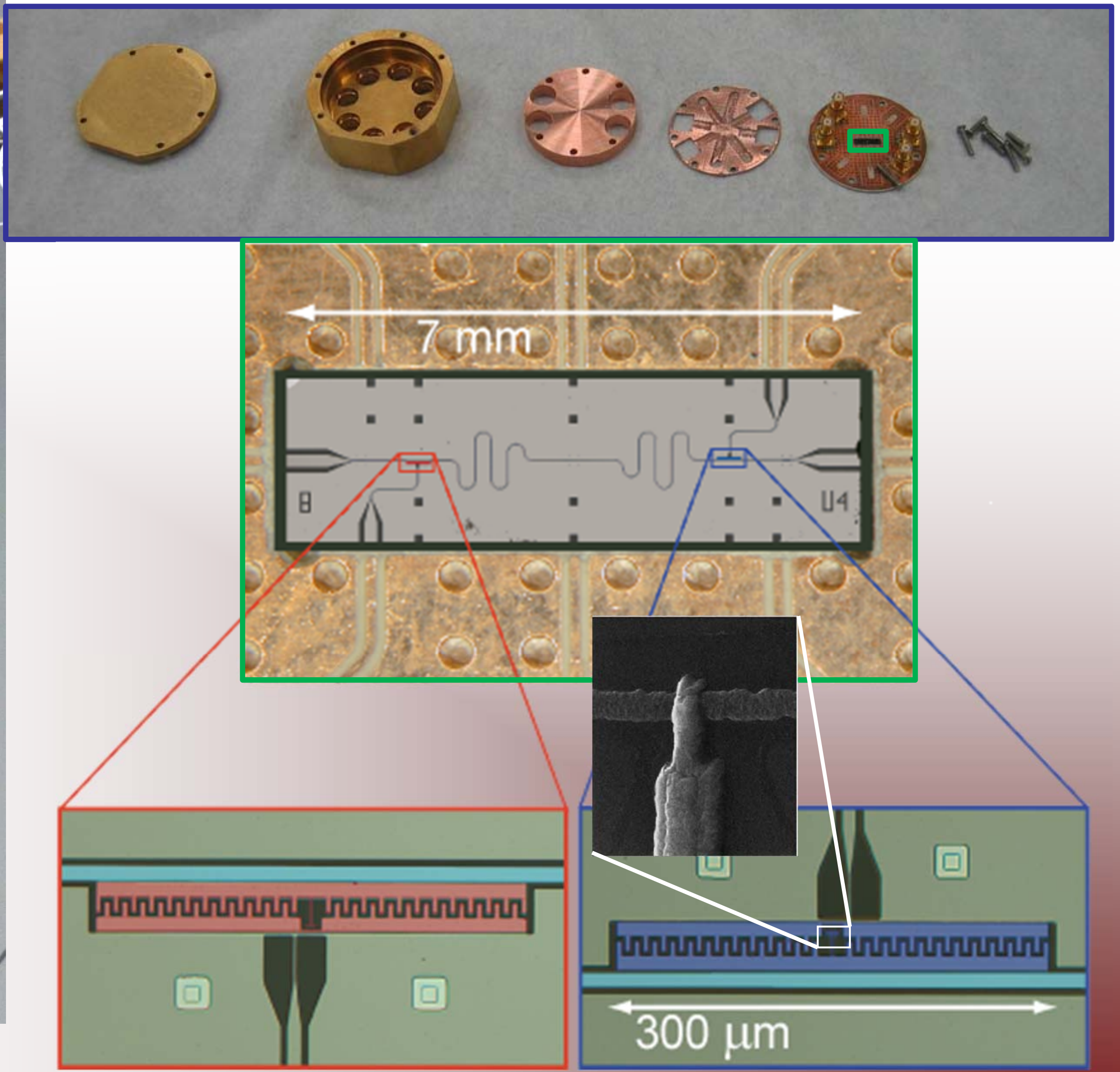
Property	QC	Accelerator	Comparison
Quality Factor	10^6	10^{11}	10^5
Frequency	4-10 GHz	1-10 GHz	1
Input power	10^{-18} W	1 W	10^{18}
Temperature	0.01 K	2K	10^2
Mode volume	$10^{-6}\lambda^3$	λ^3	10^6
E field strength	$1\ V/m$	$10^7\ V/m$	10^7

Fermilab

Millikelvin resonator characterization system

- Measure samples down to 13 mK
- Measure with powers down to <1 aW

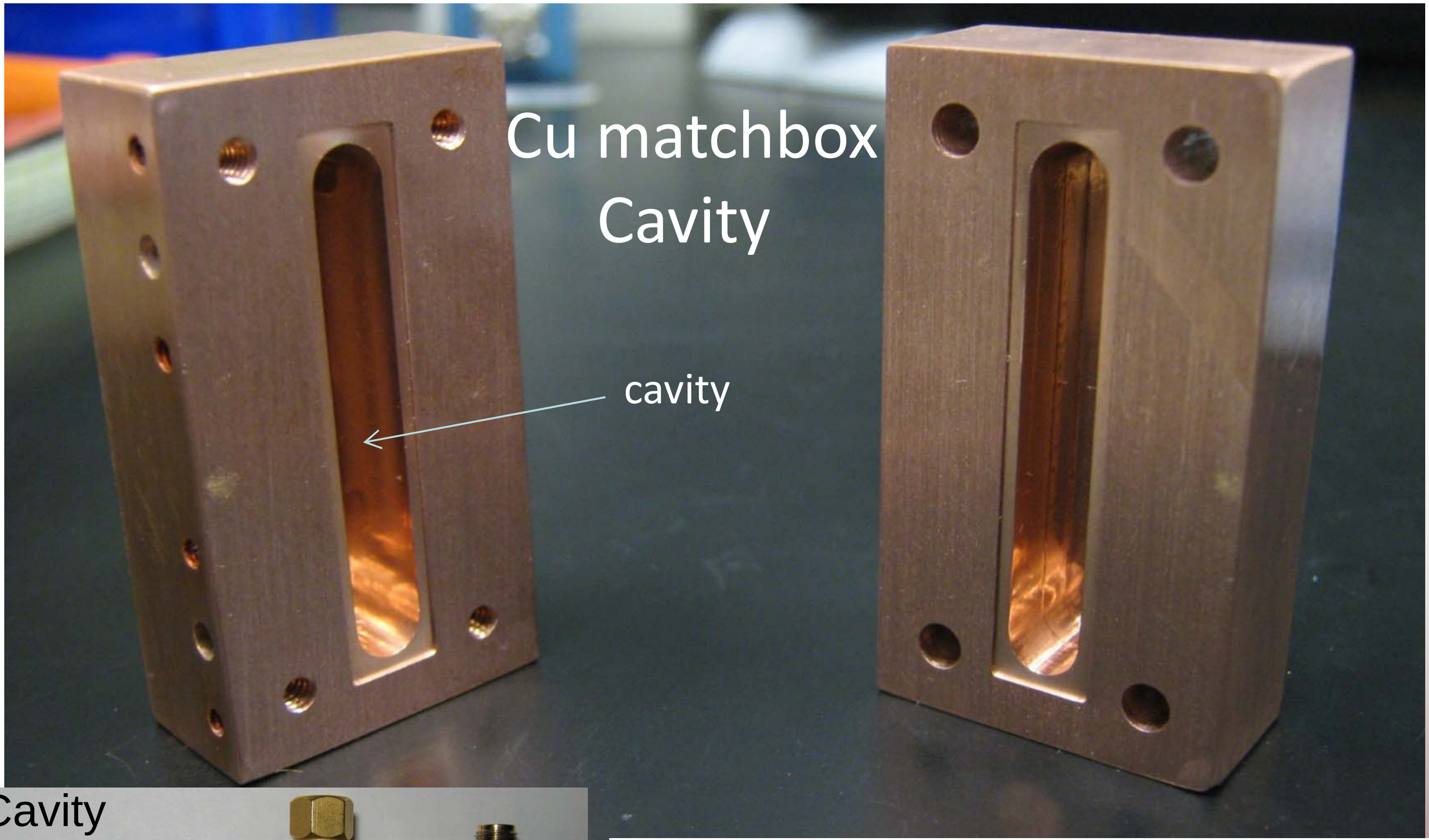


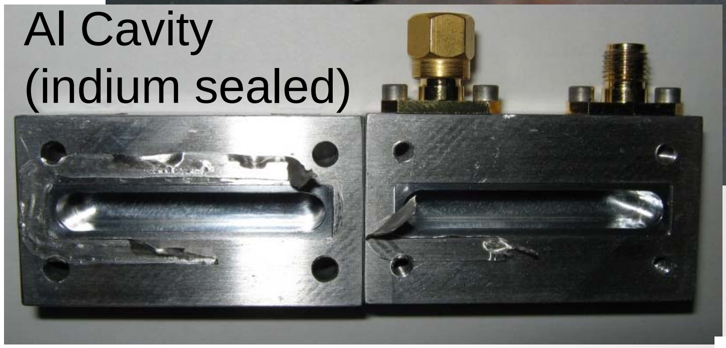


Fermilab

Now possible to couple qubits to 3D cavities

1 cm





Have tried, Cu, Nb, Al, and "solder dipped"
All SC ones achieved Q~1M

H. Paik, D. I. Schuster, et. al. PRL 107, 240501 (2011)

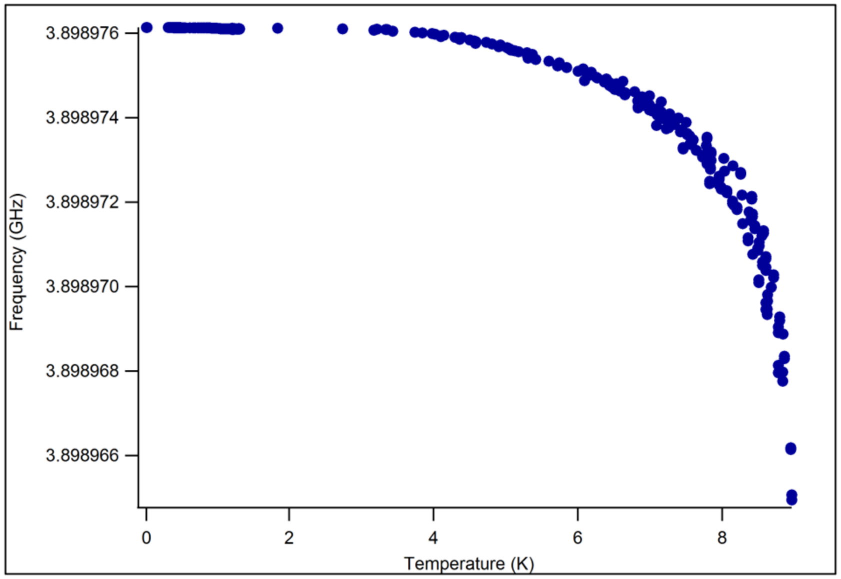
Fermilab

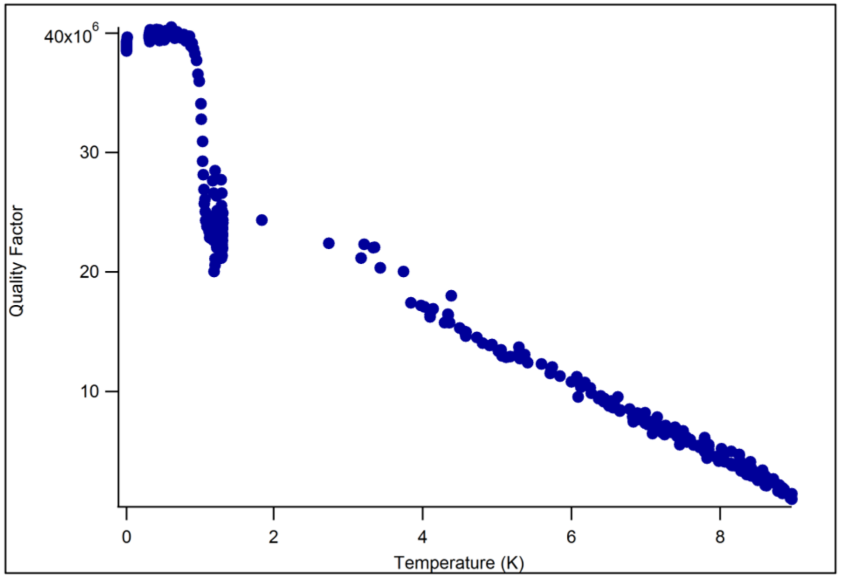
First measurements of a Fermilab Cavity at T << 1 K!!

- Fermilab cannot test below ~1.5 K
  - *This is uncharted territory!*

- Q = 40,000,000
  - *Higher than any QC qubit / resonator!*
  - *… but why isn't this 10^{10}?*

- Reasonable frequency vs temp
- Strange Q(T) dependence
- For early data, cavity temperature was not equal to fridge temperature





Fermilab

Next steps

- Try to understand why Q appears to be lower at UofC
  - Improve measurements of the Fermilab cavities
    - Modify coupling of antenna
    - Bring in expertise of cavity test group at Fermilab
    - Phase-locked loop scheme should be used for high Q
    - Add magnetic shielding

- Then:
  - Design cavity compatible with SC qubit
    - Possibly fabricate it at Fermilab
  - Dynamically tunable Q
  - Attempt to miniaturize cavities