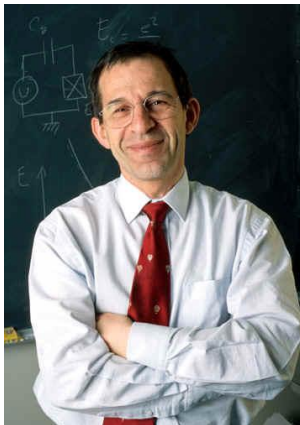


Wafer Assembled Whispering Gallery Mode Resonator

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Thanks to:

Kurtis

Nick

Rob Schoelkopf

QuLab

RSL Lab

Desired Goals

- Study superconducting thin film quality factor
- ‘Wafer-Scalable’ Circuit QED architecture
- Allow flux bias, copper cavity

Means:

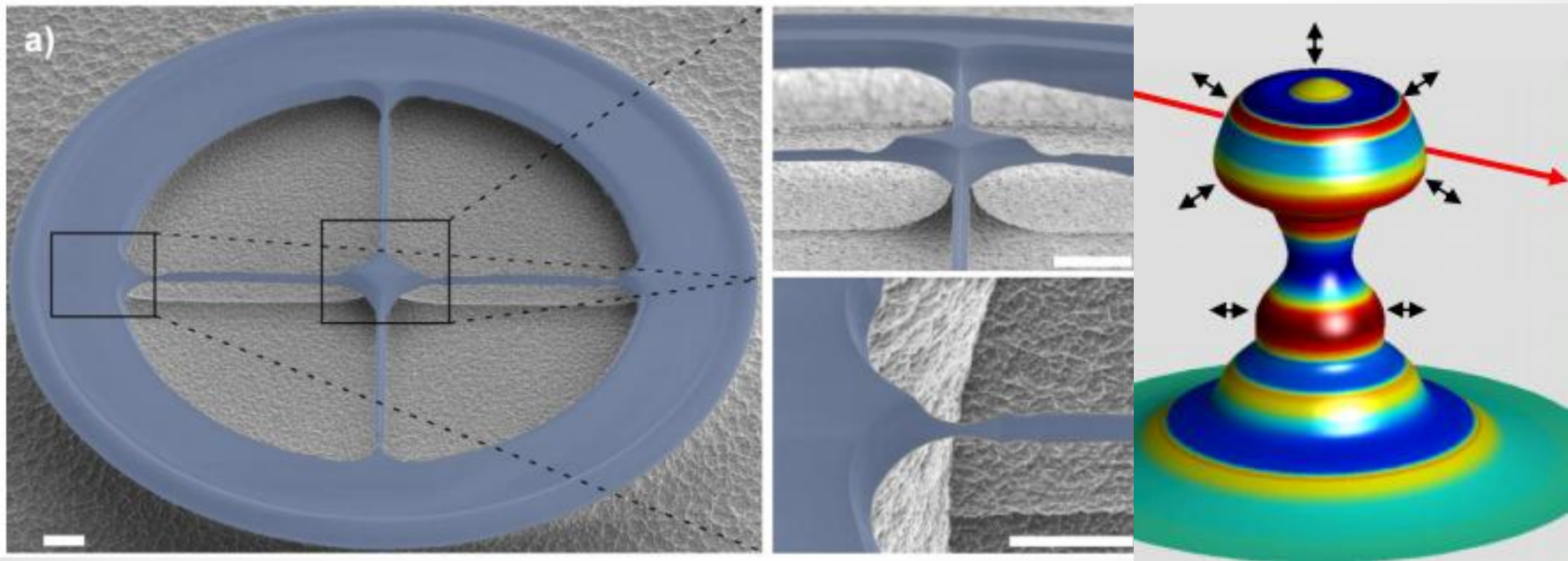
- Confine EM Waves in vacuum between patterned Aluminum films
 - Keep fields away from lossy dielectric and copper walls
 - Mode control
- Simple, robust geometry



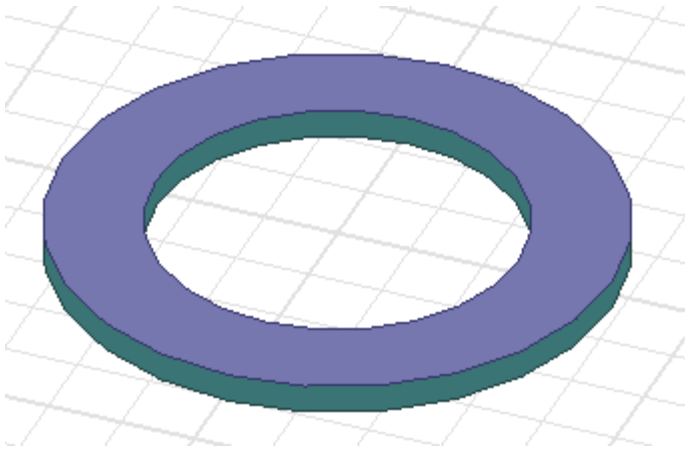
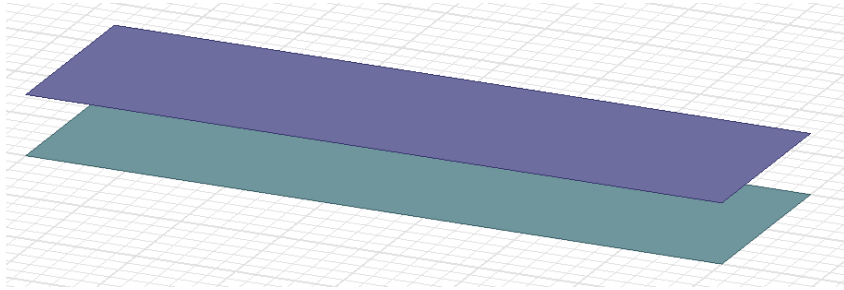


Whispering Gallery Resonators

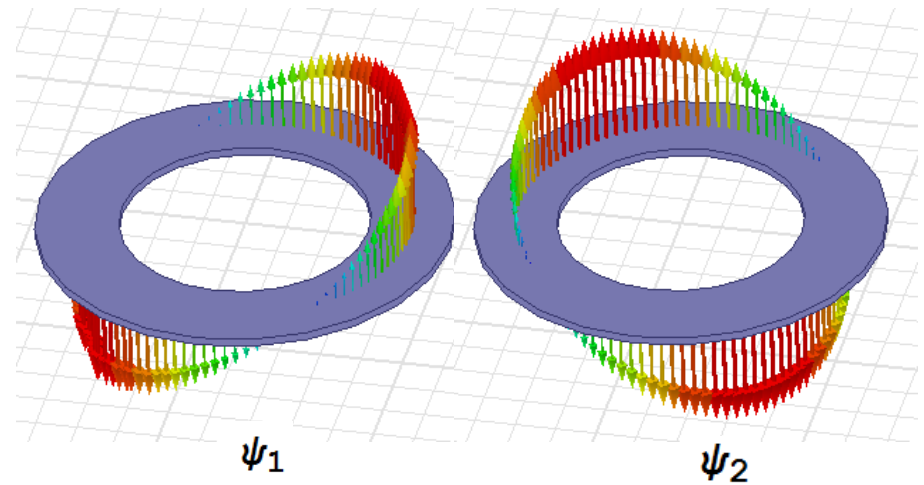
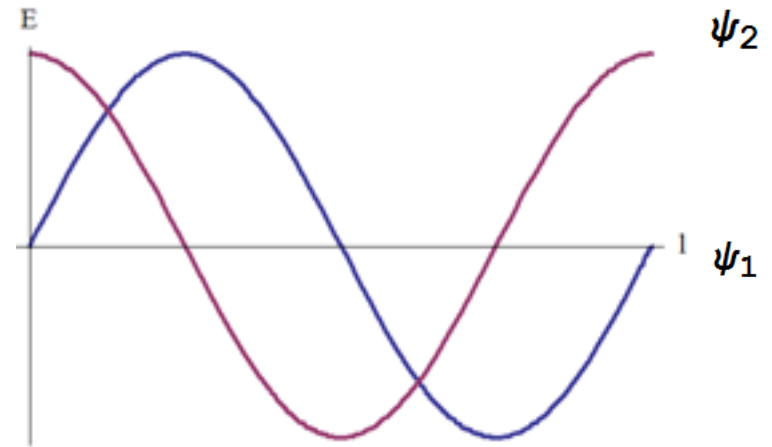
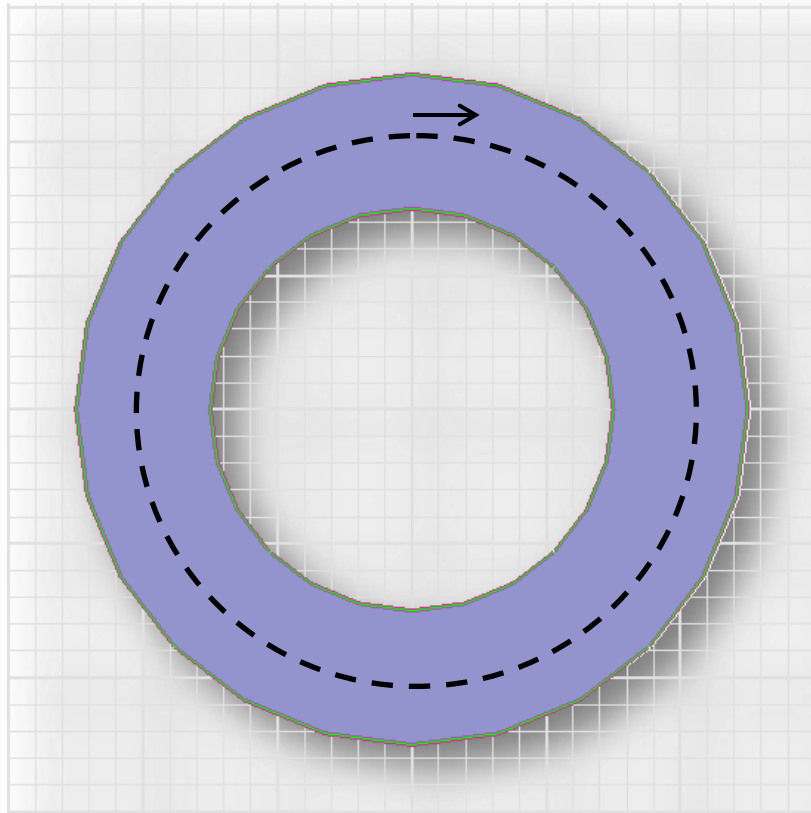
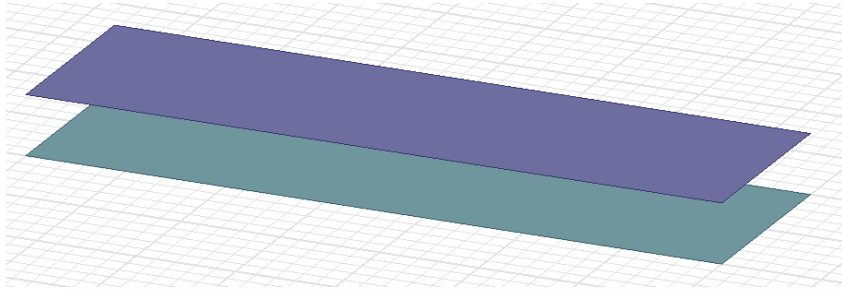
- Dielectric spherical structure
- High $Q = 10^{10}$, remove wave from unhealthy material
- Liquid droplets / glass spheres



Transmission Line Ring – Idea Recap



1D Description – 2 Degenerate Ground Modes



Lift Degeneracy

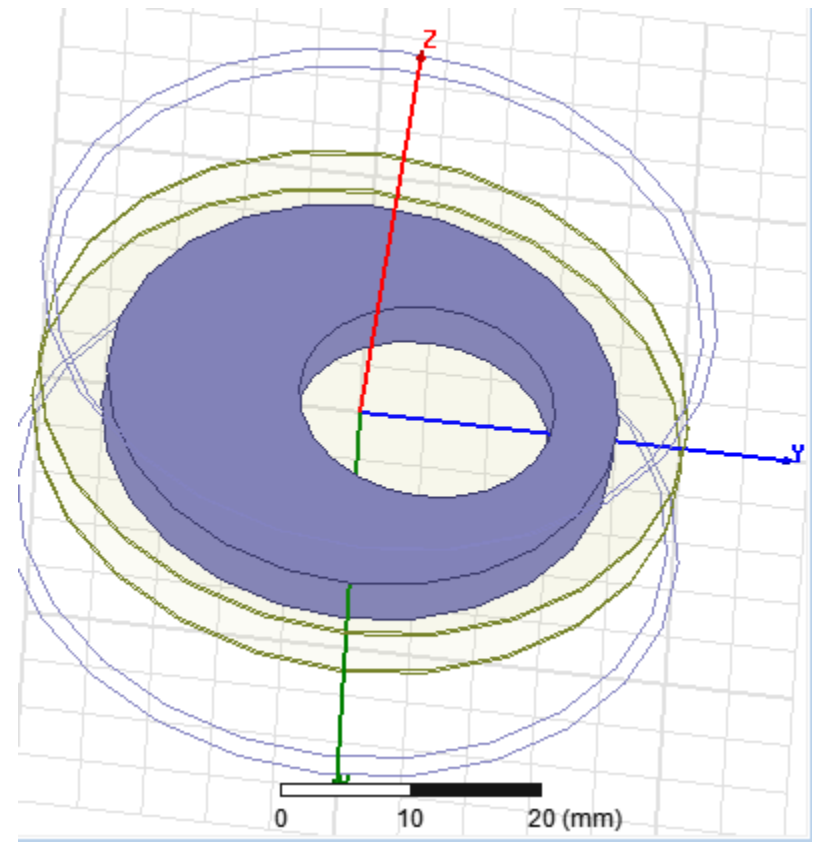
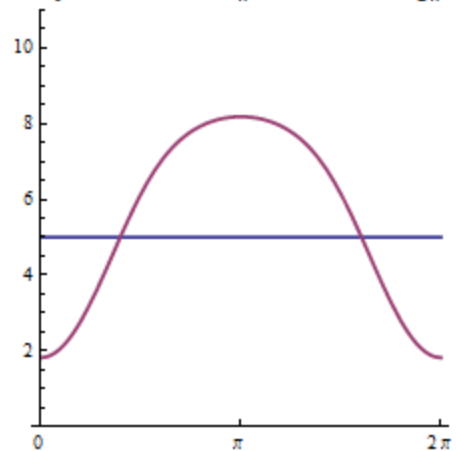
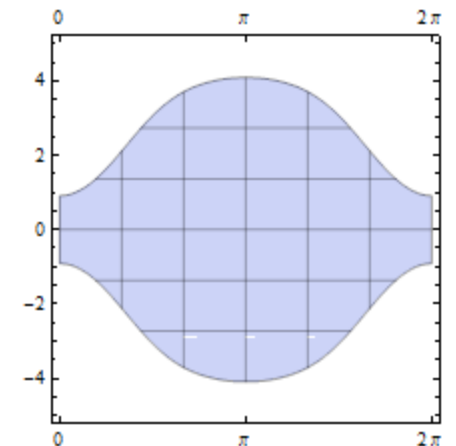
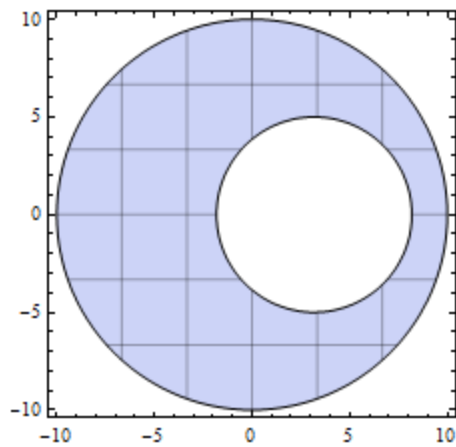
Simplified impedance
view from top

$$Z \propto \sqrt{\frac{L}{C}}$$

What the Photon
sees along its path
of travel

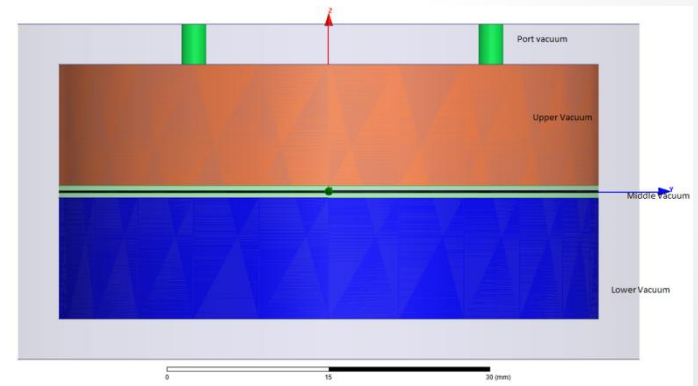
An effective 1D
admittance
for the photon along
its path

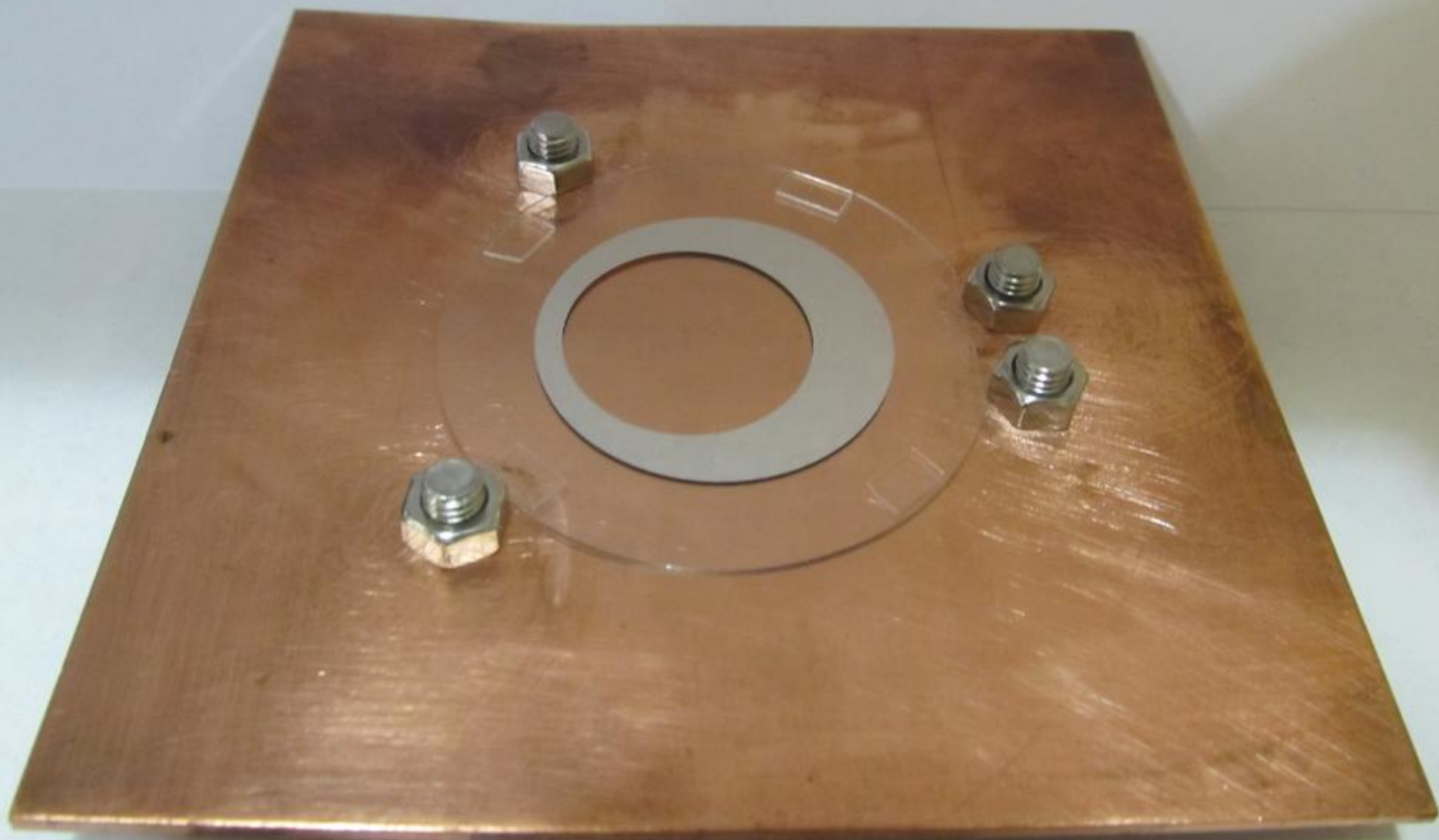
$$Y_{\infty \text{ TL}} = \frac{1}{377 \Omega} \frac{w}{d}$$

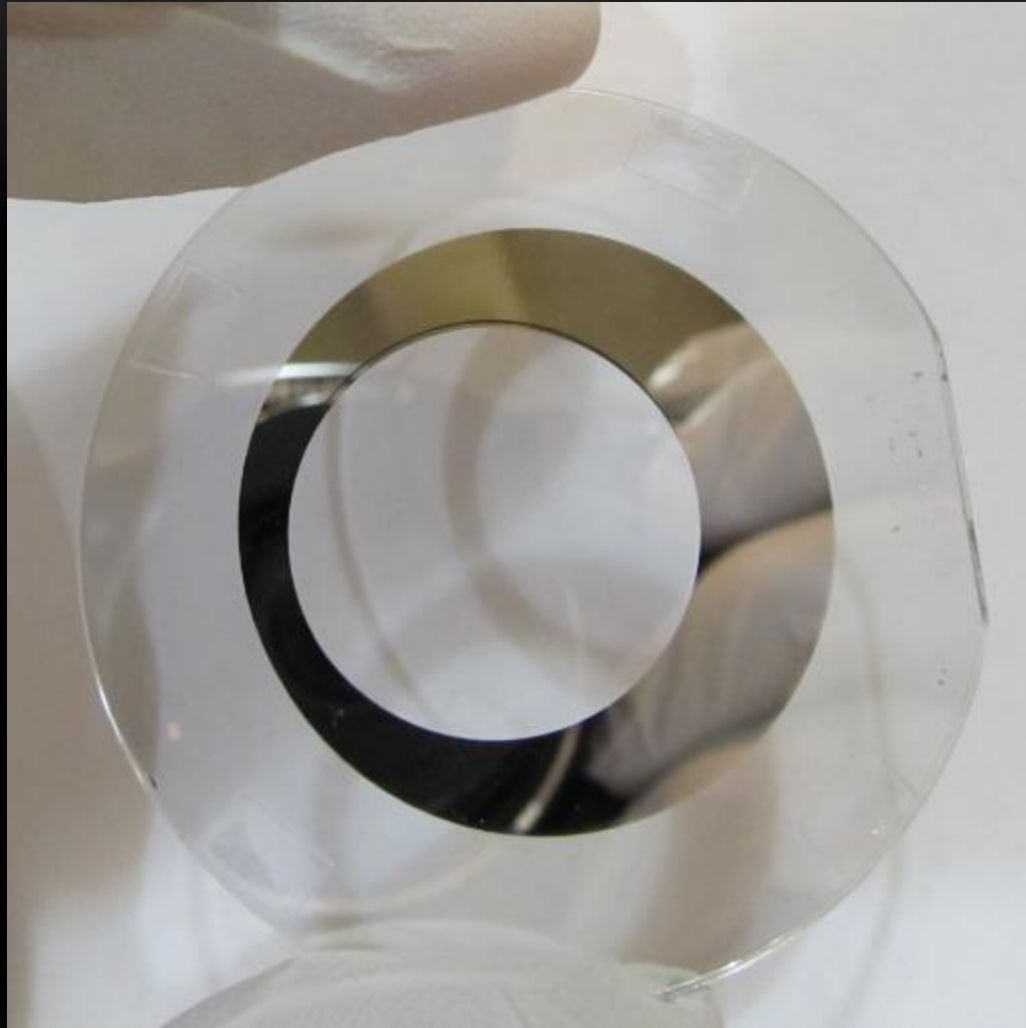


Simulation Interesting Points

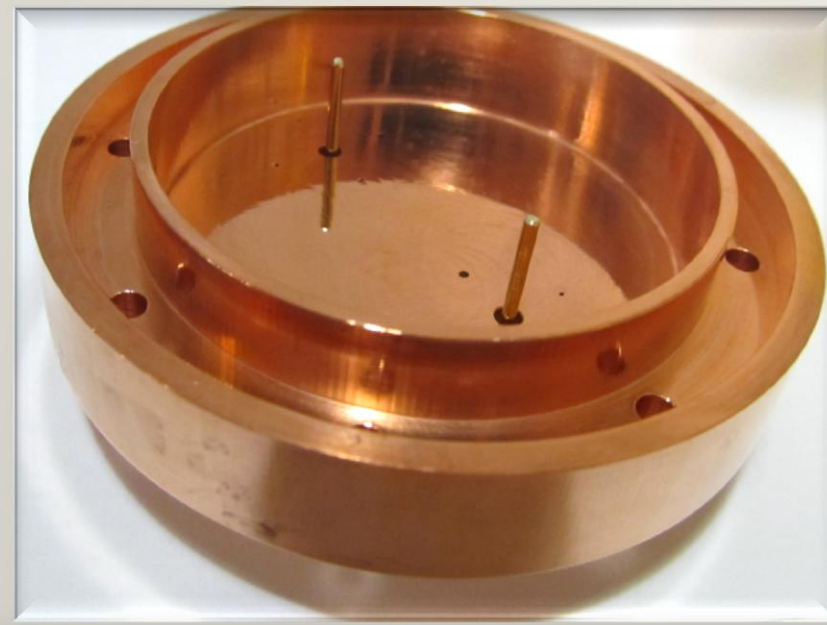
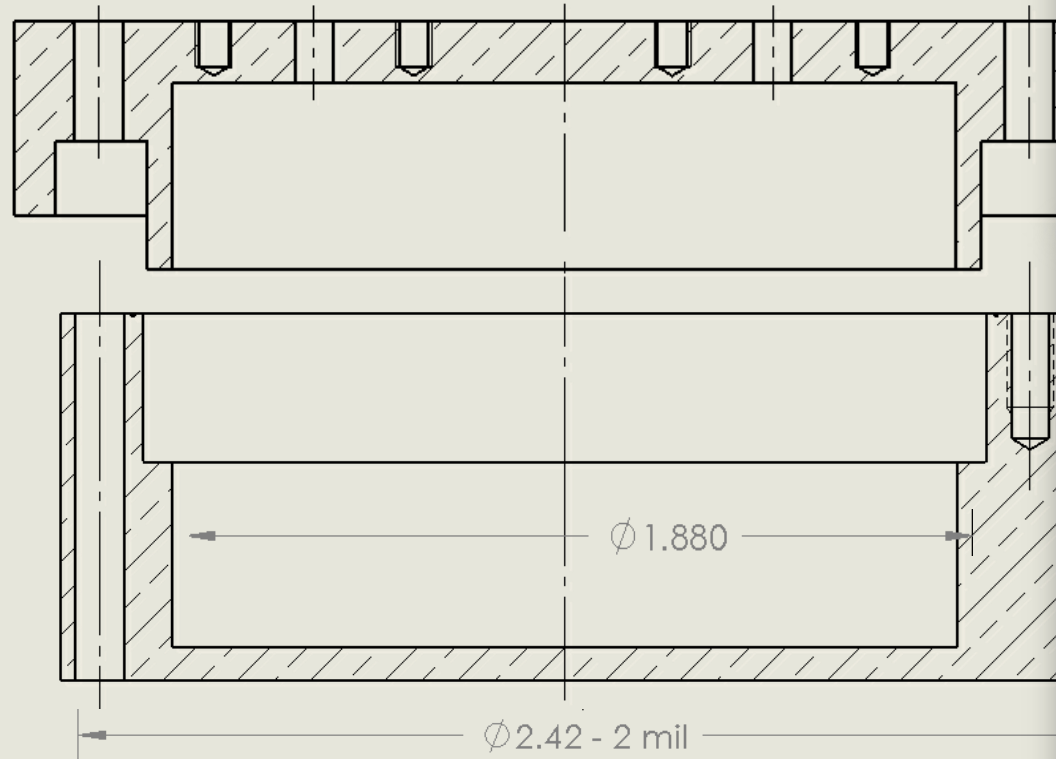
- Simulation indicate that displacement of a few mm and rotation of a few degrees reduce the internal Q by only a factor of 2
- Simulations suggest internal quality factors in the 10s of millions are achievable.
- Middle Vacuum Participation Ratio: ~97%
- Calculated induced current per photon: ~90 nanoamps
- Verified simulation self-consistency between different ways to extract coupling and internal Q's

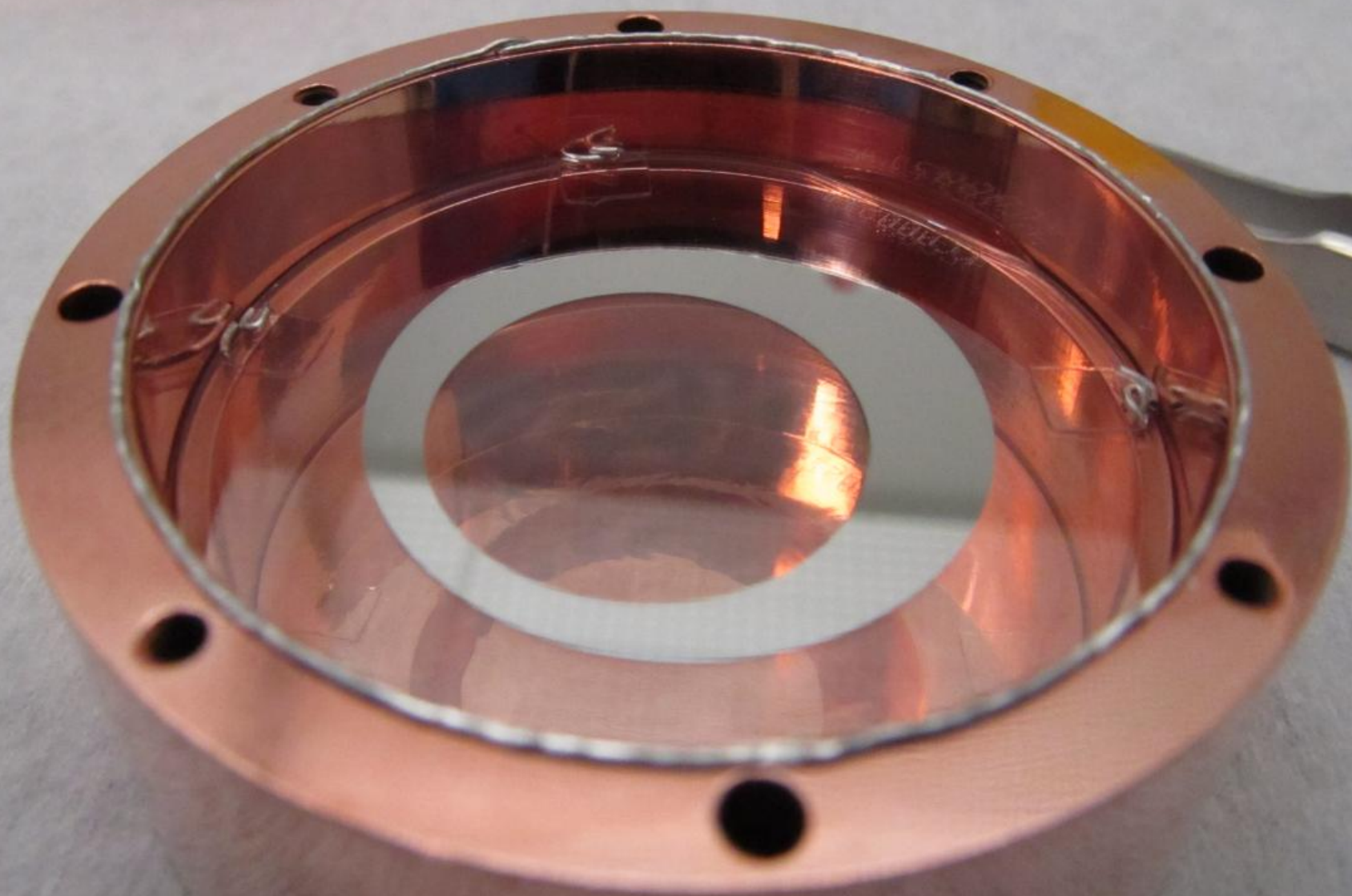




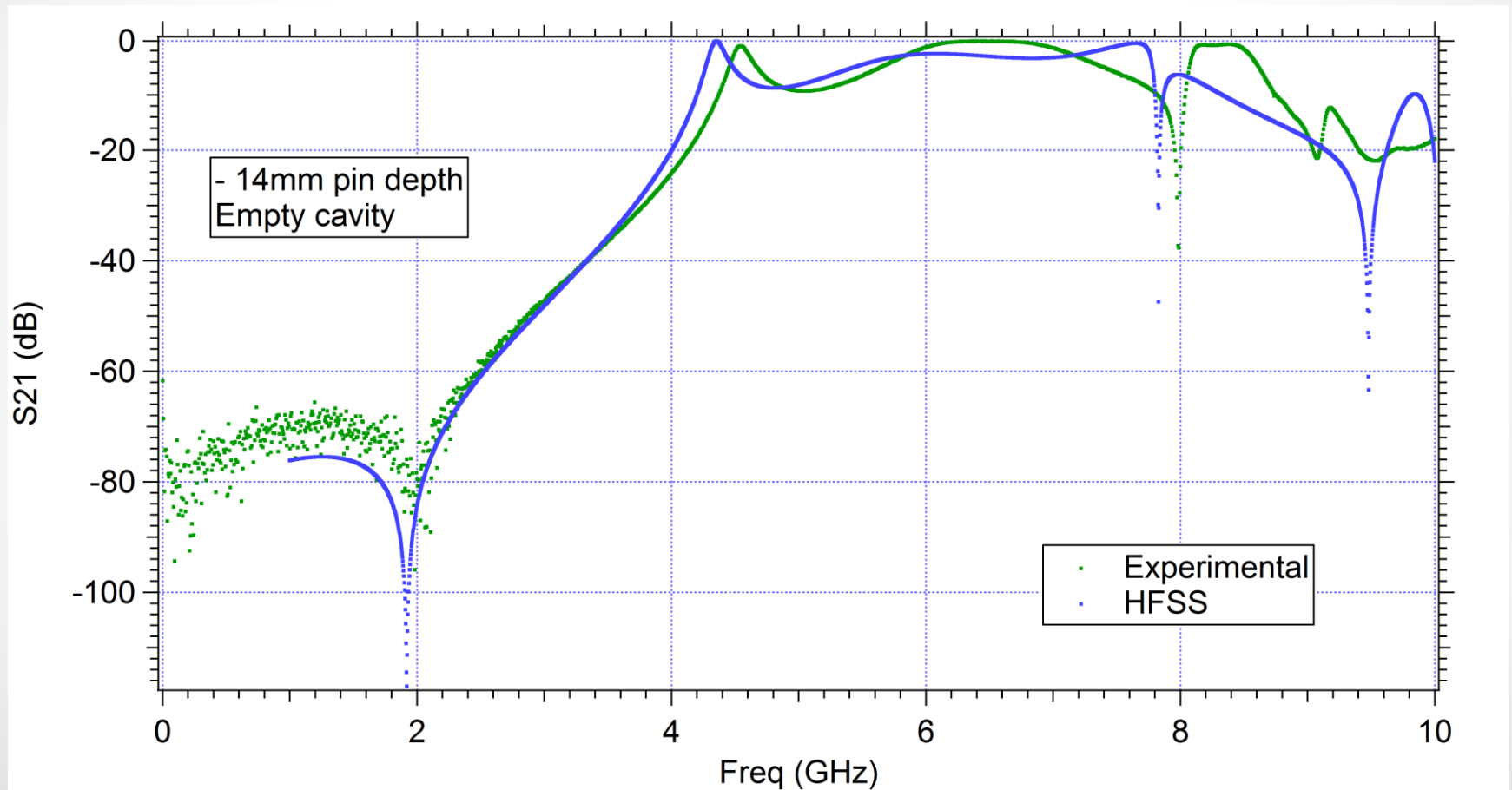


Sample Holder

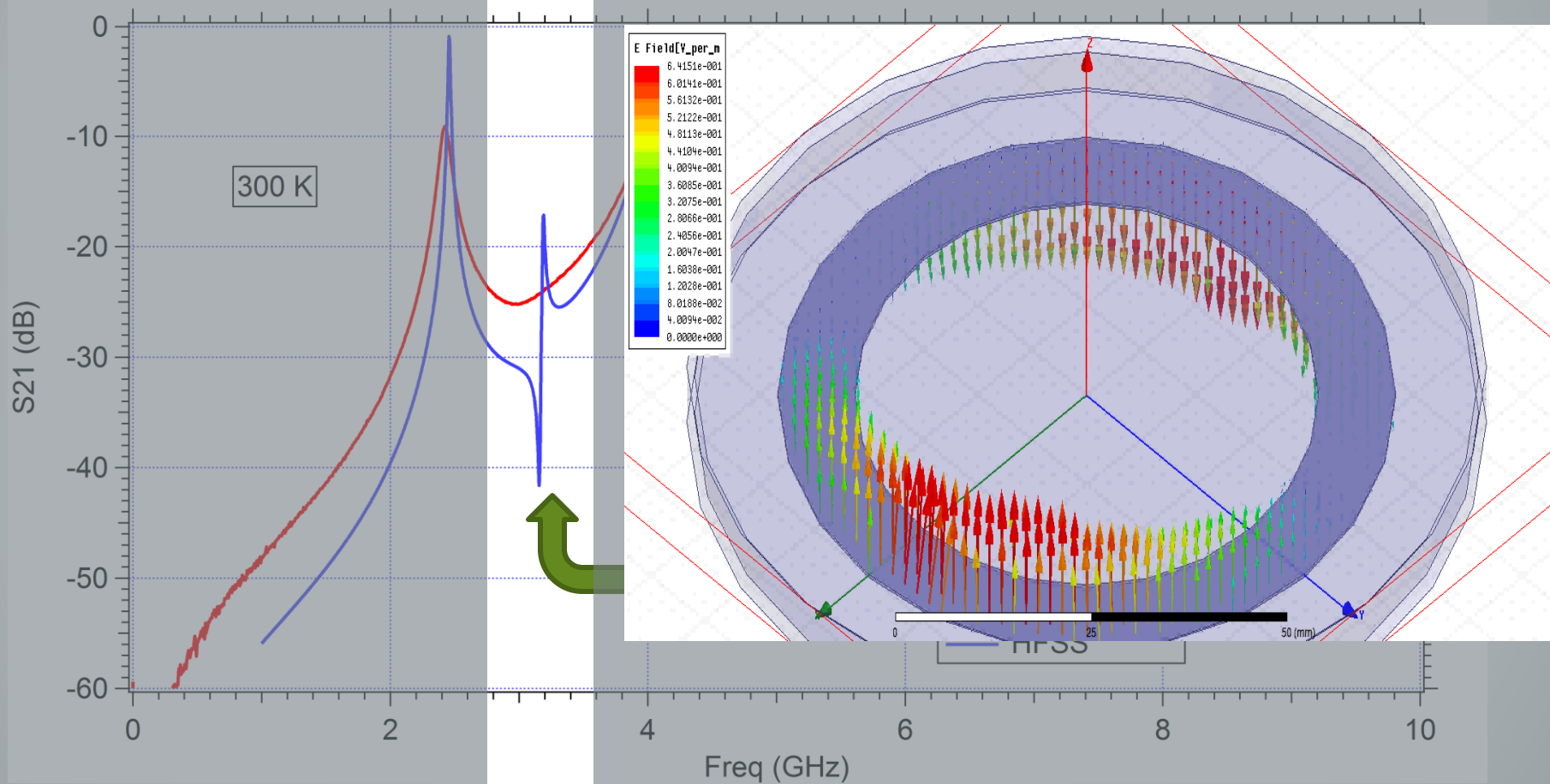




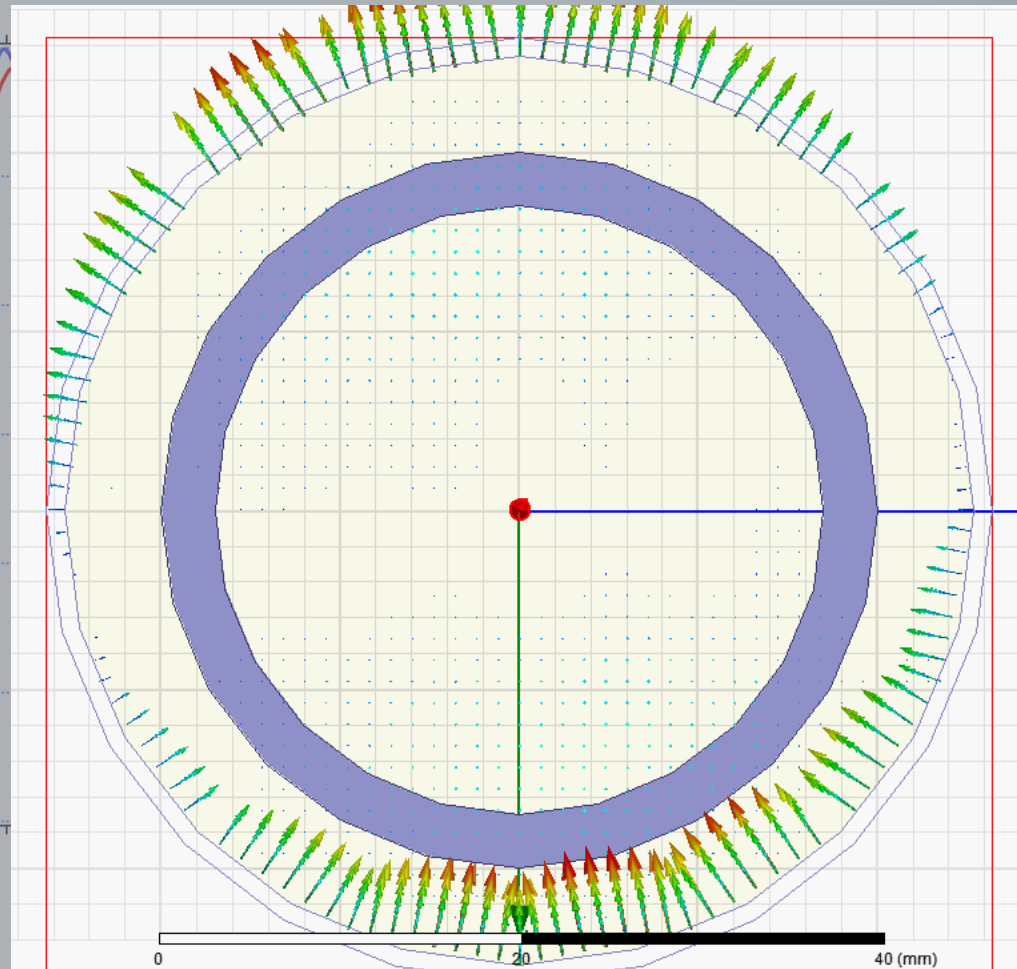
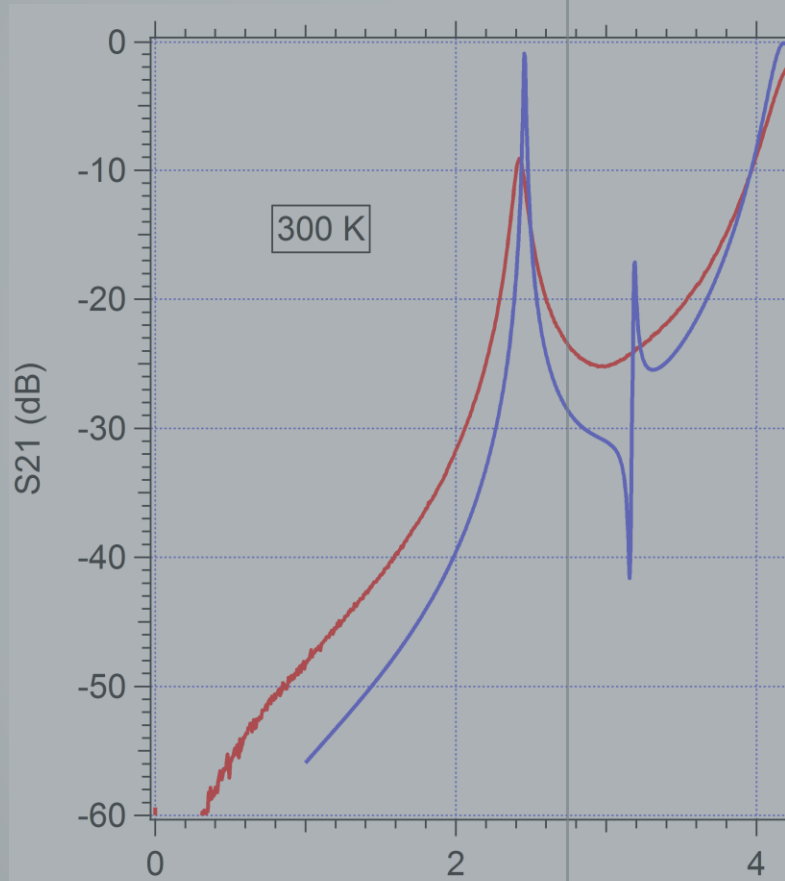
Empty cavity 300 K simulation v. experiment



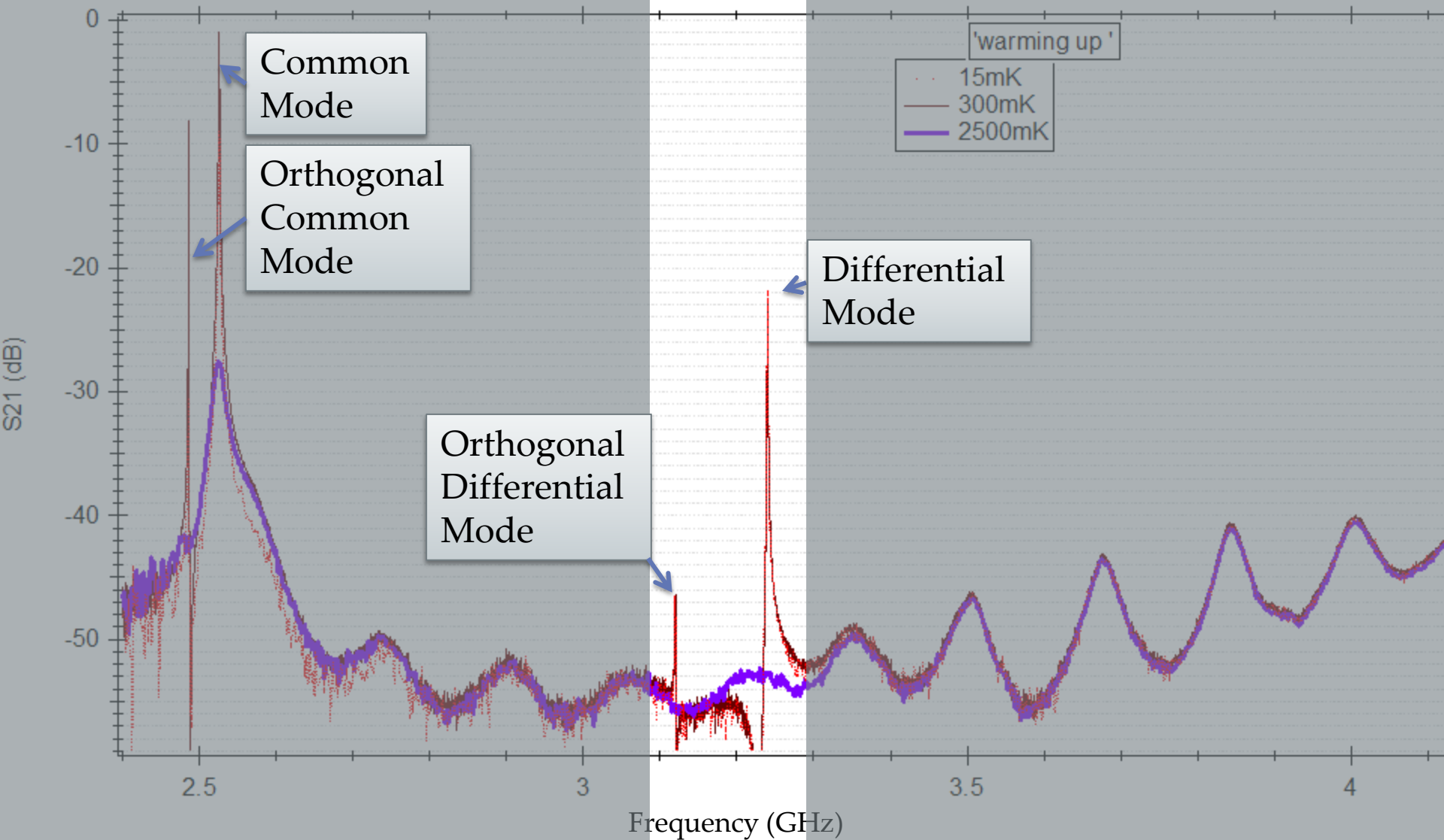
300 K simulation against experiment S21



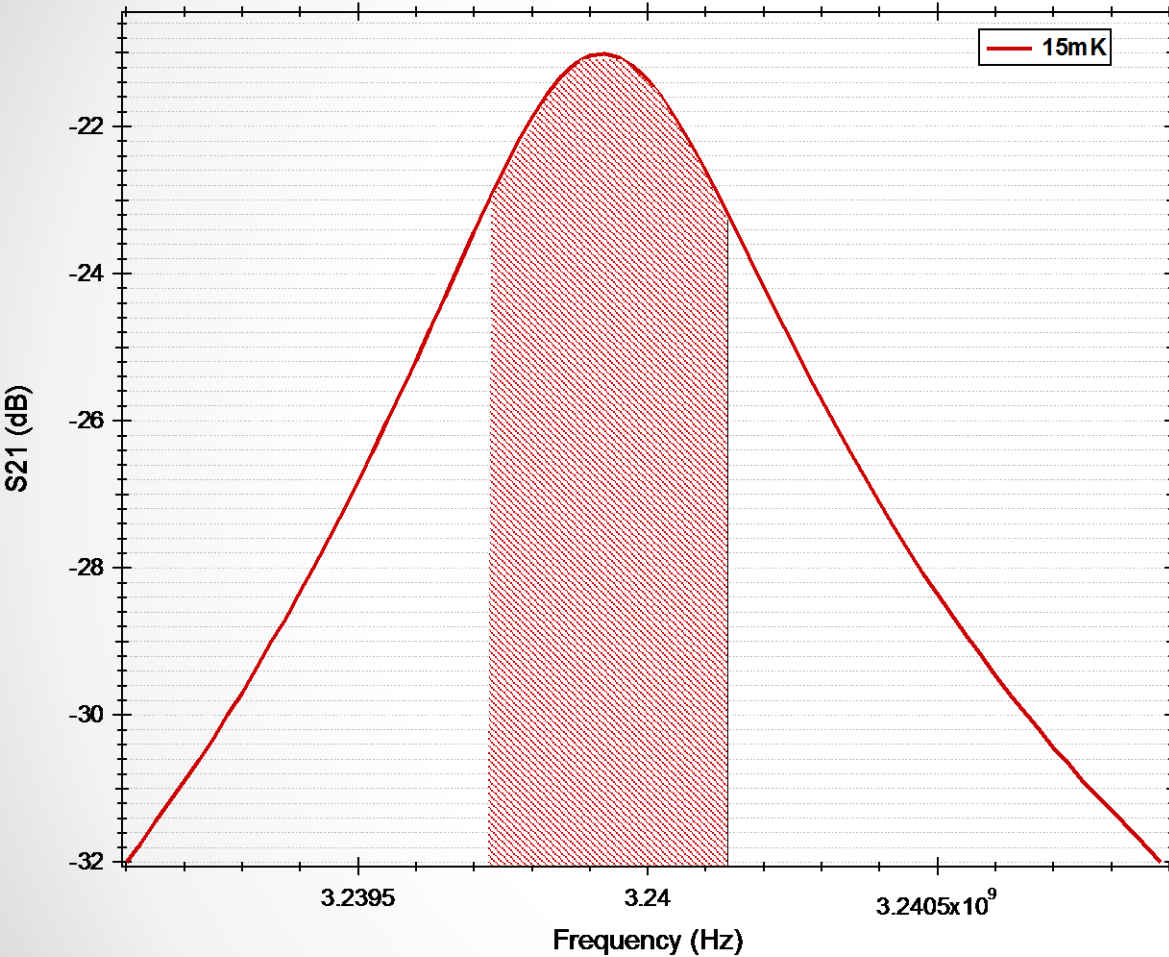
300 K simulation against experiment S21



Profile



Whispering Mode



In line

Freq (GHz)		Qint	Qcouple
3.305	DM	7,050	$\sim 10^6$
2.516	CM	11,500	40,000

Hanger

Freq (GHz)		Qint	Qcouple
3.192	DM	9,600	10^6
2.517	CM	16,500	330,000

Changes

- Thicker film: 300nm vs. 50nm
- Added Superconducting Shield
- Replaced crushable indium shim with Teflon
- 1 ring resonator is patterned: chicken wire
- Used heavy weight instead of magnet in cooking wafer sandwich

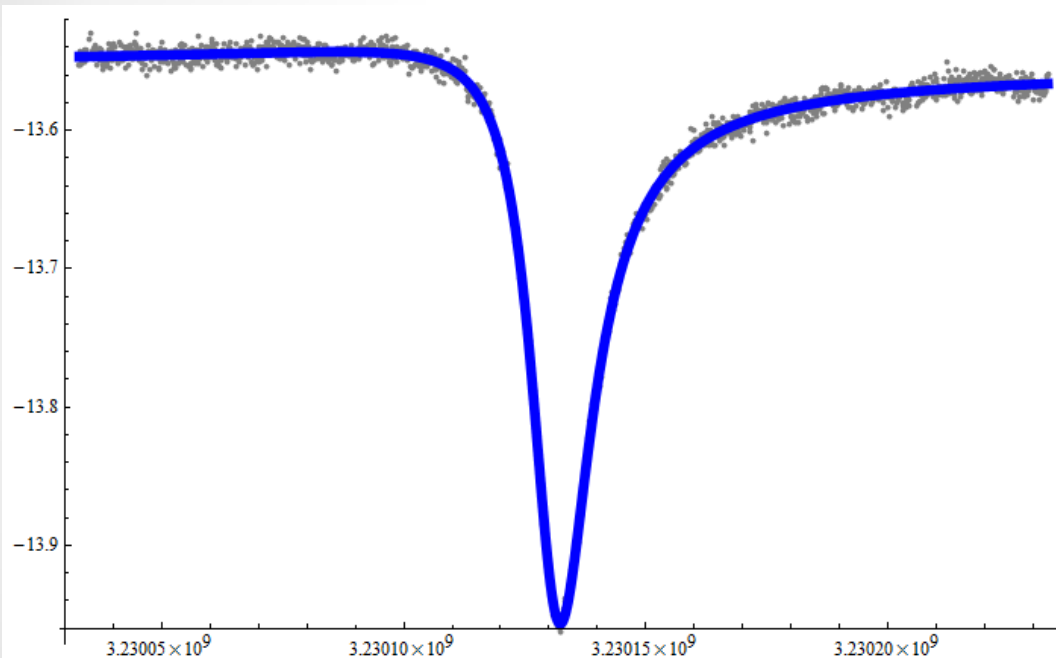
Current Samples

In line

Freq (GHz)		Qint	Qcouple
3.305	DM	125,000	$\sim 10^6$
	CM	Not yet	measured

Hanger

Freq (GHz)		Qint	Qcouple
3.230	DM	220,000	$4 \cdot 10^6$
2.521	CM	88,000	50,000



Next ...

- Aluminum Sample Holder
- Cryoperm magnetic shield
- Instrument to investigate losses in different material
- Multiple resonator structures
- Josephson Junction integration & qubits



QUANTRONICS LABORATORY

Department of Applied Physics

Yale University

