Progress Towards a Novel Hybrid Rydberg-Atom-Microwave-Cavity Quantum System

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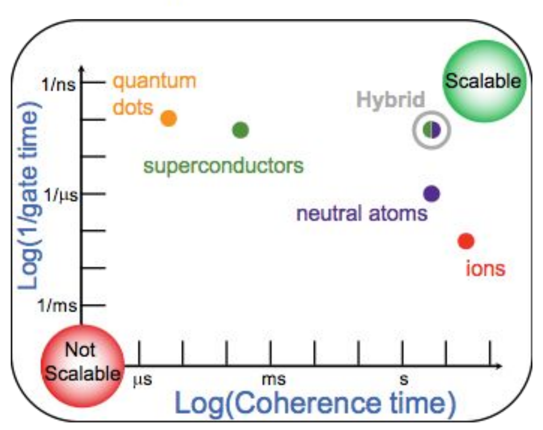
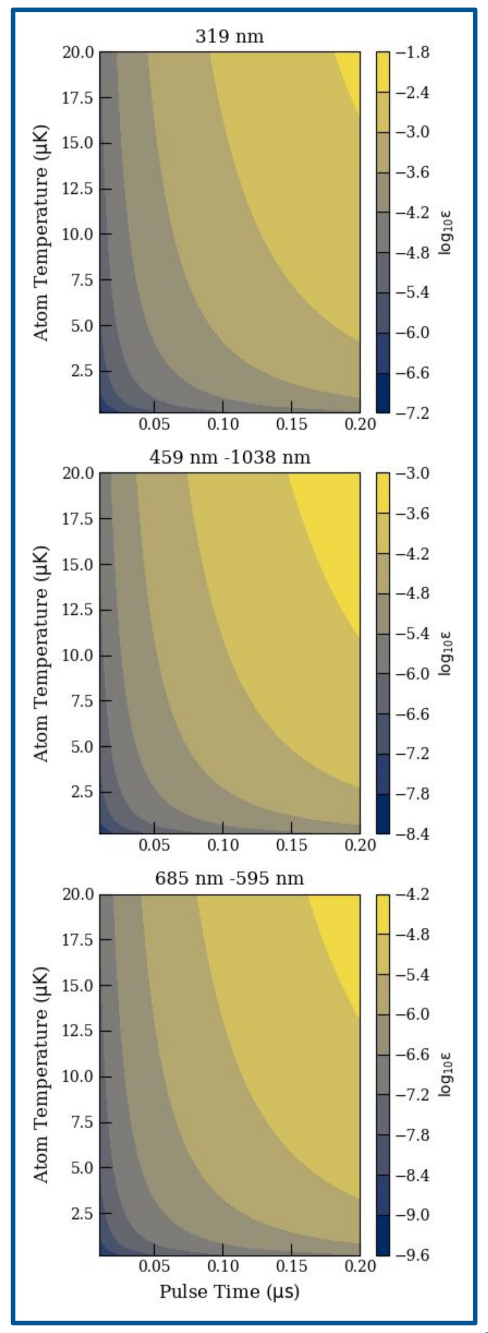
Motivation[1]

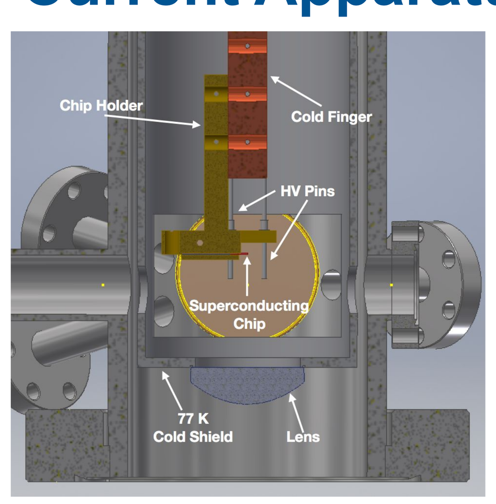
- Hybrid Rydberg-atom-Superconductor platforms make potential scalable quantum architectures, and transduction platforms [1]
- Require atom-surface distances from 1μm to 200μm [1][2][3]
- DC polarizability $\alpha_0 \sim n^7$[4]
- Bulk Resonator requires 100 μm atom-surface distance. 10x CPW design
- Quadrupole-Dipole scheme is minimally sensitive to doppler shifts

$$\Delta\omega_{doppler} = \Delta\mathbf{k} \cdot \mathbf{V}$$





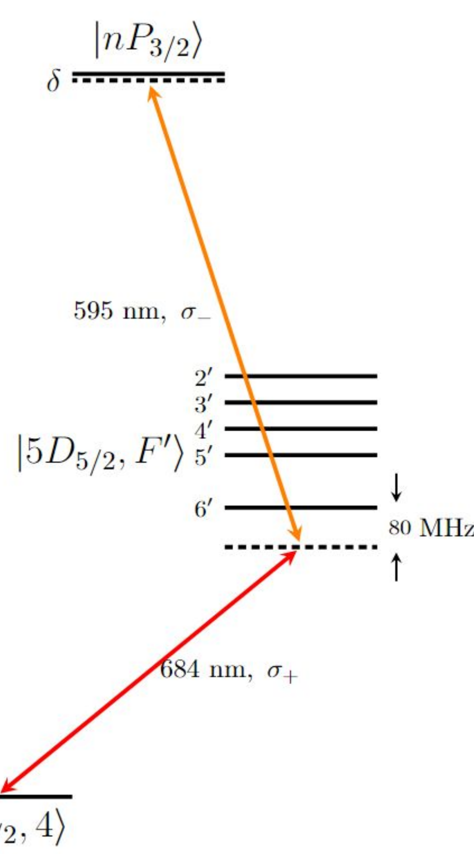
Current Apparatus

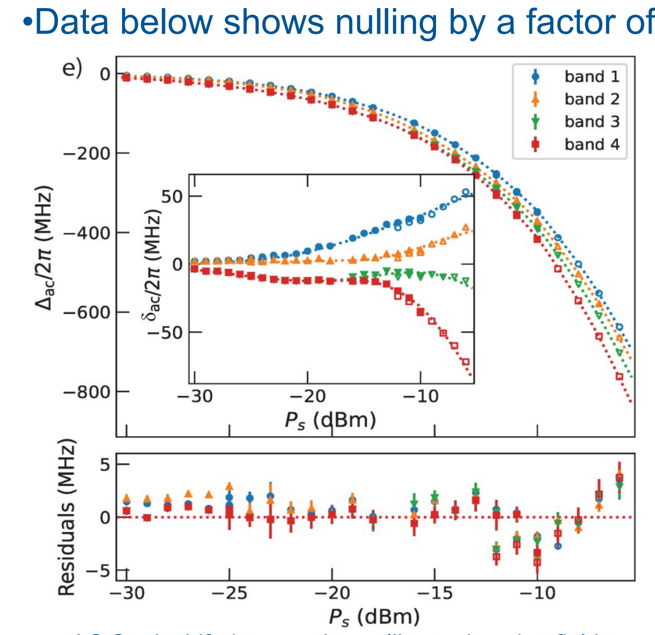


- Device designed for Rydberg cavity QED experiments
- MOT Formed 5 mm below CPW
- Atoms loaded from 77k environment
- FORT, Collection, Rydberg optics on translation stages
- Loaded atoms can be moved into CPW interaction region

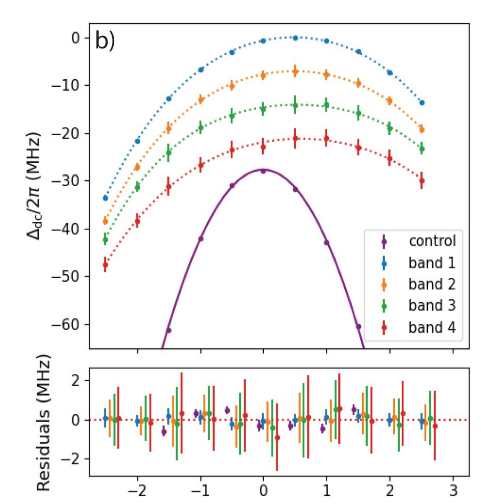
Rydberg

- Microwave fields can dress the $52P_{3/2}$ states with $51D_{3/2}$ and $51D_{5/2}$ states
- P and D states have opposite signed polarizability, reducing in DC polarizability of Dressed states
- Data below shows nulling by a factor of 7 in $52P_{3/2}$





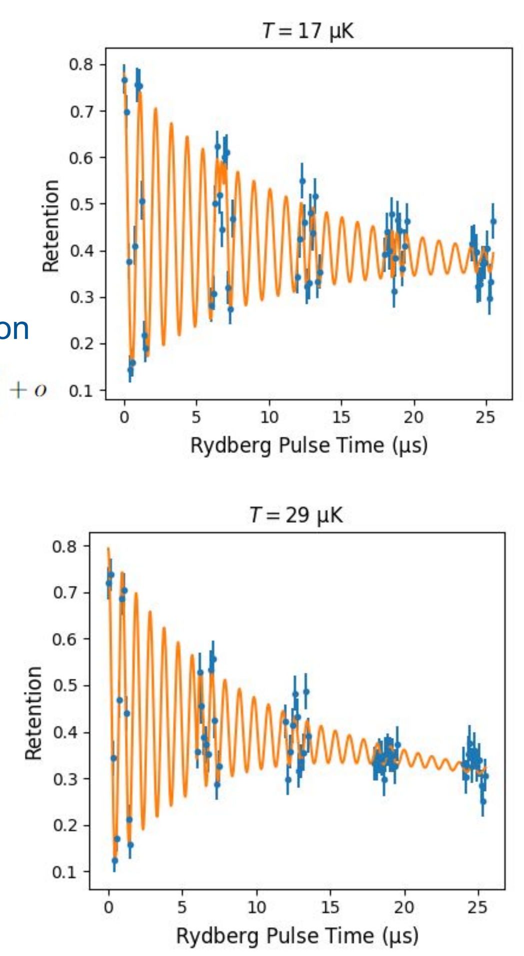
AC Stark shift data used to calibrate dressing field



Dressed Rydberg states with reduced polarizability

- Rydberg Rabi between |4,0> and $|52P_{3/2}$ 1/2>
- Fit to decaying oscillation

$$P(t) = \frac{a}{2}\left(1 + \cos(\Omega t)e^{-t/T}\right) + o$$



Rydberg Rabi oscillations at different atom temperatures

T (μK)	Ω/2π (MHz)	τ(μs)	Ωτ/2π
17	0.9	9.9 ± 1.6	9 ± 1
29	1.0	6.6 ± 0.8	6.9 ± 0.8

- Initial Rydberg data shows promising fidelity
- Fidelity is dependent on atom temperature
- Expected source of dephasing is atom localization

New Atom-Cavity System

Composition:

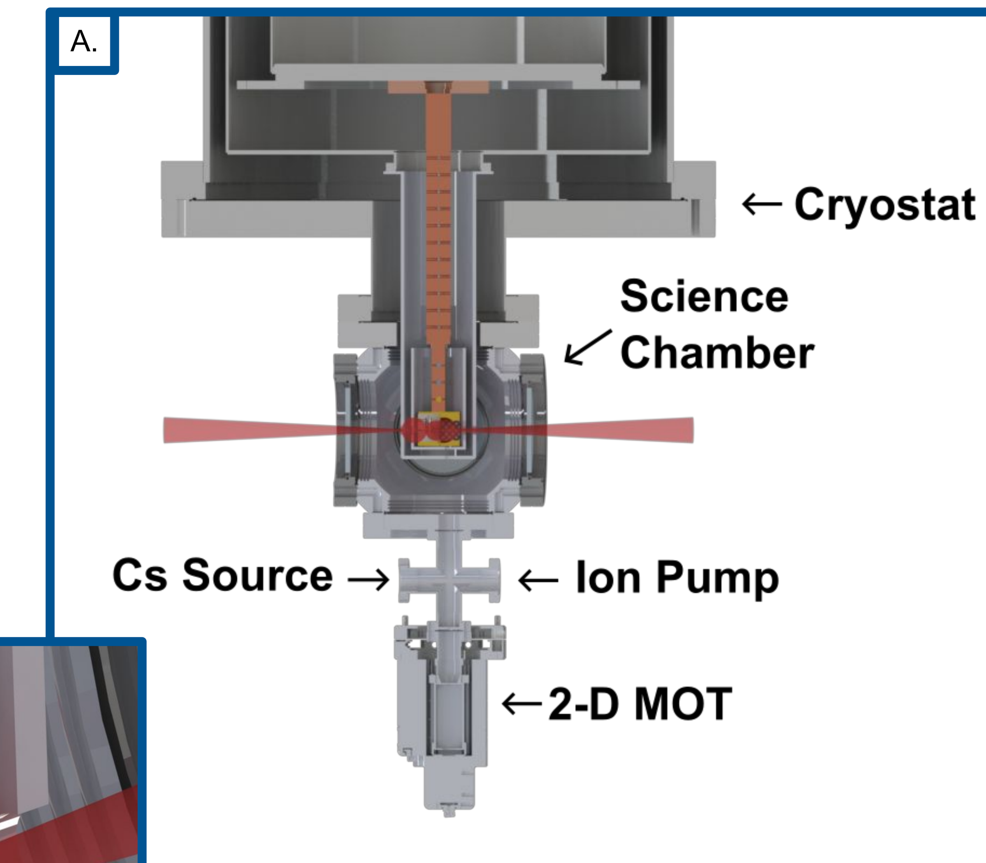
- Cryostat with 77K and 4K Heat Shields

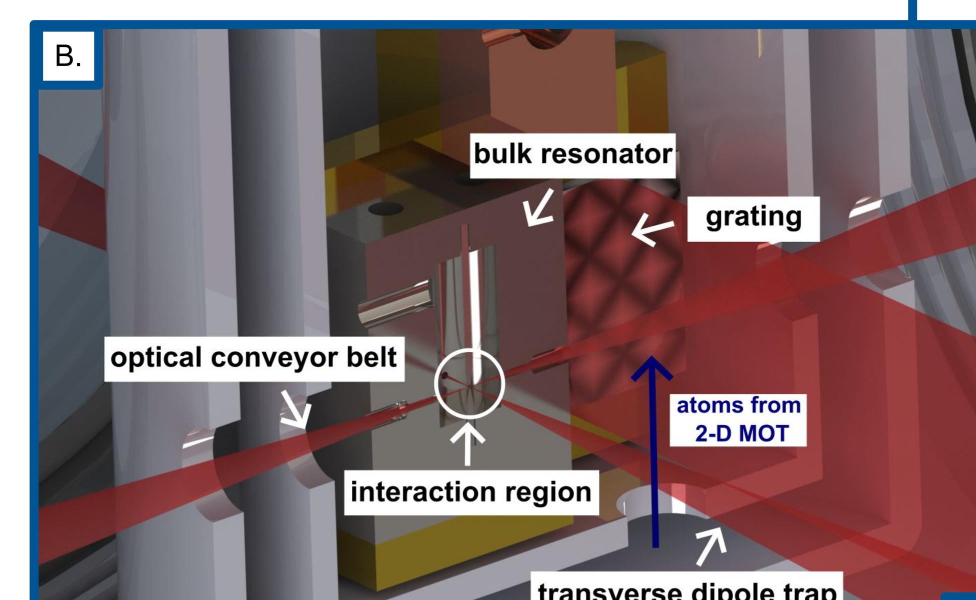
Outside Cryostat Heat Shields:

- 2D MOT with Push Beam Transport

Inside Cryostat Heat Shields:

- UHV from cryo-pumping
- 3D Grating MOT [5]
- Bulk Microwave Superconducting Resonator
- Optical Conveyor Belt at 915nm [6]
- Transverse ODT at 938nm inside Resonator

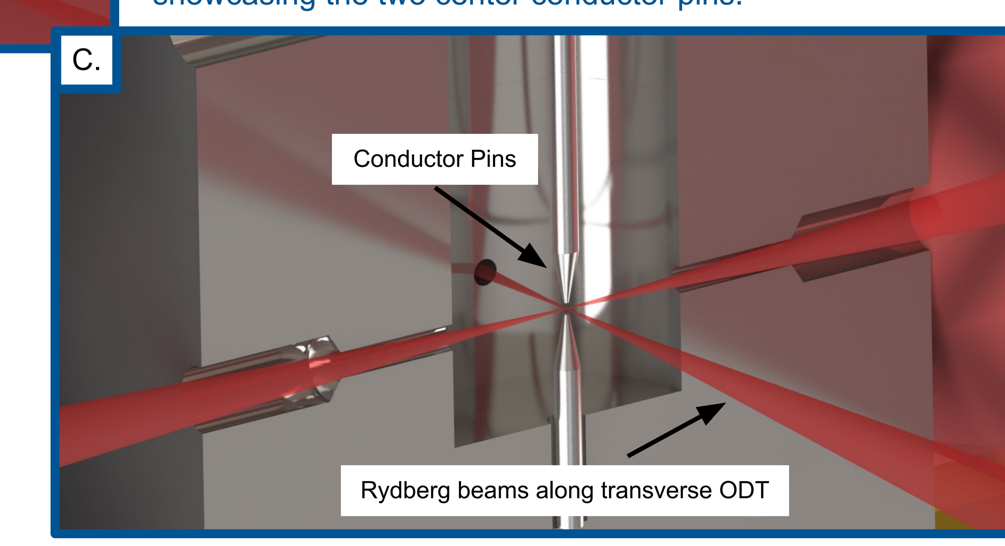




A. - Novel Atom-Cavity System. The push beam transport between the 2D MOT and 3D MOT is omitted.

B. - Components within the cryostat's heat shields. The conveyor belt transports atoms from the grating MOT into a transverse ODT within the resonator's interaction region.

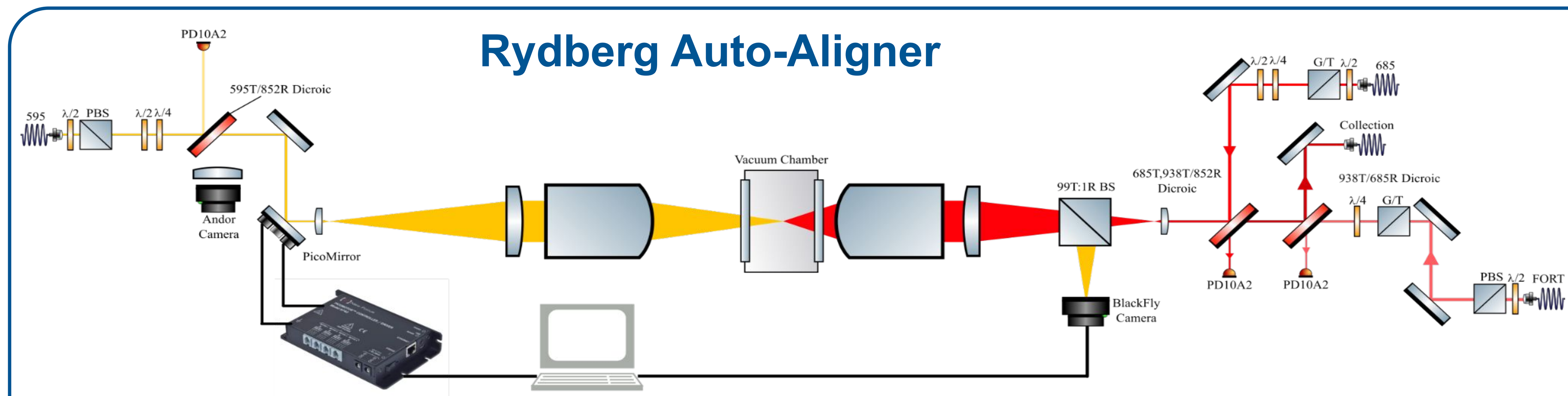
C. - Close up of the resonator's interaction region, showcasing the two center conductor pins.

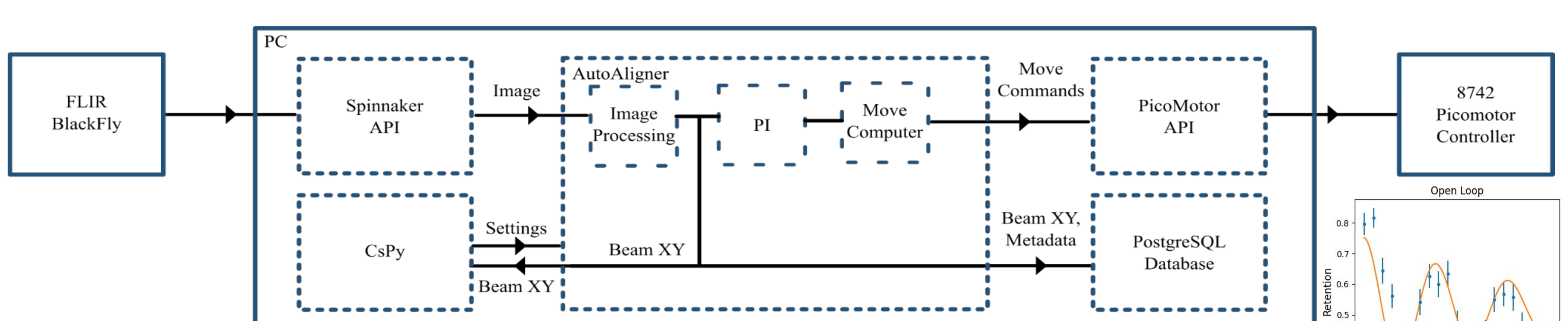


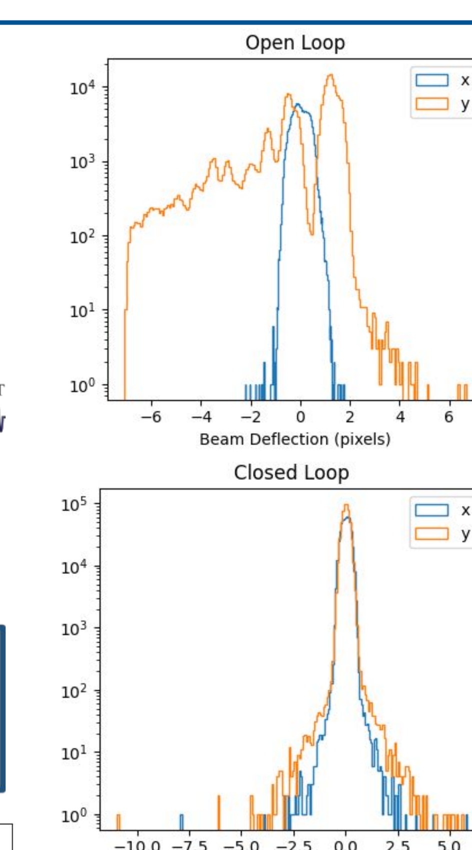
Physical Properties of the Bulk Resonator:

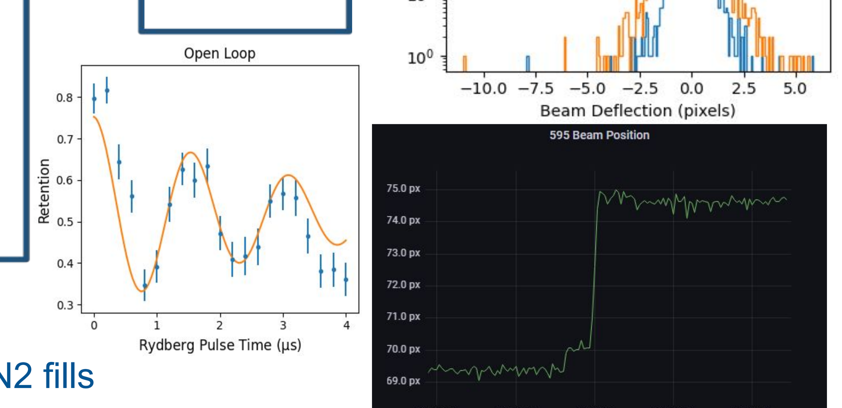
- Resonance = 5.3 GHz
- Resonator Material = Silver-coated Titanium
- Conductor pins concentrate field mode at large distances from surfaces
- Center conductor pin separation = 200 μm
- Resonator Q at 77K = 600
- Resonator Q at 4K = 8000

Rydberg Auto-Aligner



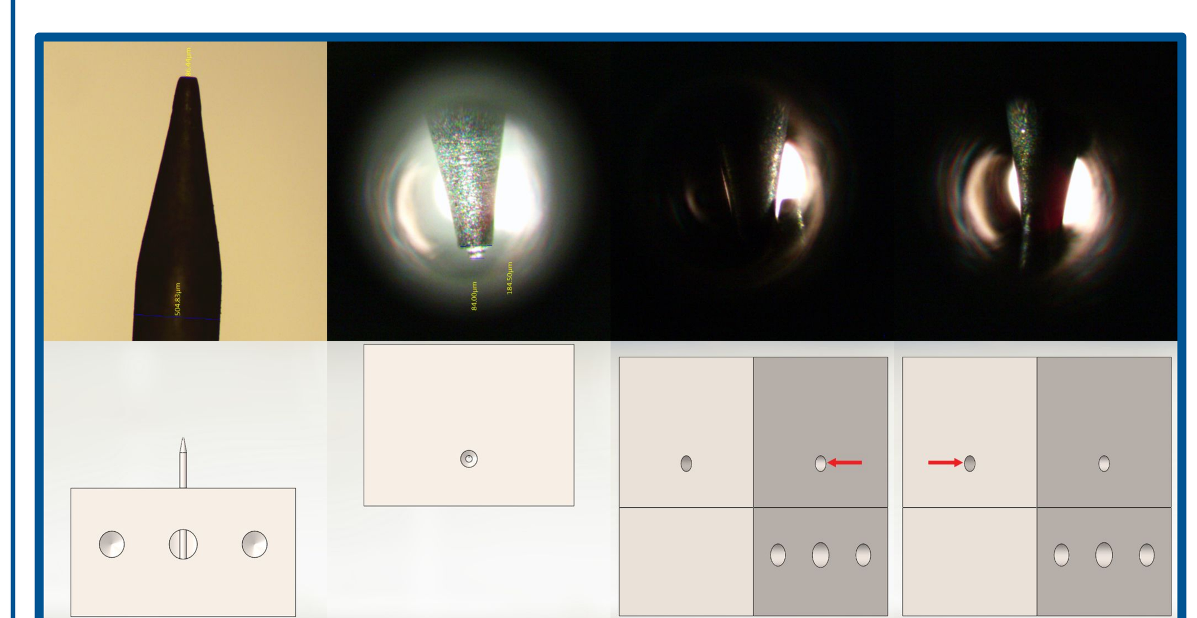






- 595 nm beam (from left) re-imaged in other optical system, at the cell
- Newport PicoMotor-actuated mirror provides feedback
- Steady state beam drift below 400 nm in closed loop operation
- Beam data and images are stored for future analysis
- System resilient to slow temperature drifts ~1K
- And Fast jumps due to LN2 fills

Bulk Resonator Fabrication Status



- A prototype of the bulk resonator has been fabricated
- Manufacturing difficulties led to crashing of the two center conductor pins
- This is shown under microscope to the left
- Slight transverse misalignment of pins severely reduces resonator Q
- Using different techniques, other resonator prototypes are being fabricated

We have an open position for Post-Doctoral Researchers in experimental atom-microwave interface. Contact Mark Saffman at msaffman@wisc.edu for more information.

References

[1] J. D. Pritchard *et al*, Phys. Rev. A **89** 010301(R) (2014)
[2] A. Anferov *et al*, Phys. Rev. Applied **13** 024056 (Feb 2020)
[3] M. Kaiser *et al*, Phys. Rev. Research **4** 013207 (Mar 2022)
[4] Gallagher, T. F. Rydberg atoms. Cambridge University Press, Cambridge, (1994)
[5] C. C. Nshii *et al*, *Nature Nanotech* **8**, 321–324 (2013)
[6] G. T. Hickman *et al*, Phys. Rev. A **101**, 063411 (2020)