Novel Ion Trap for Fibre Cavity integration

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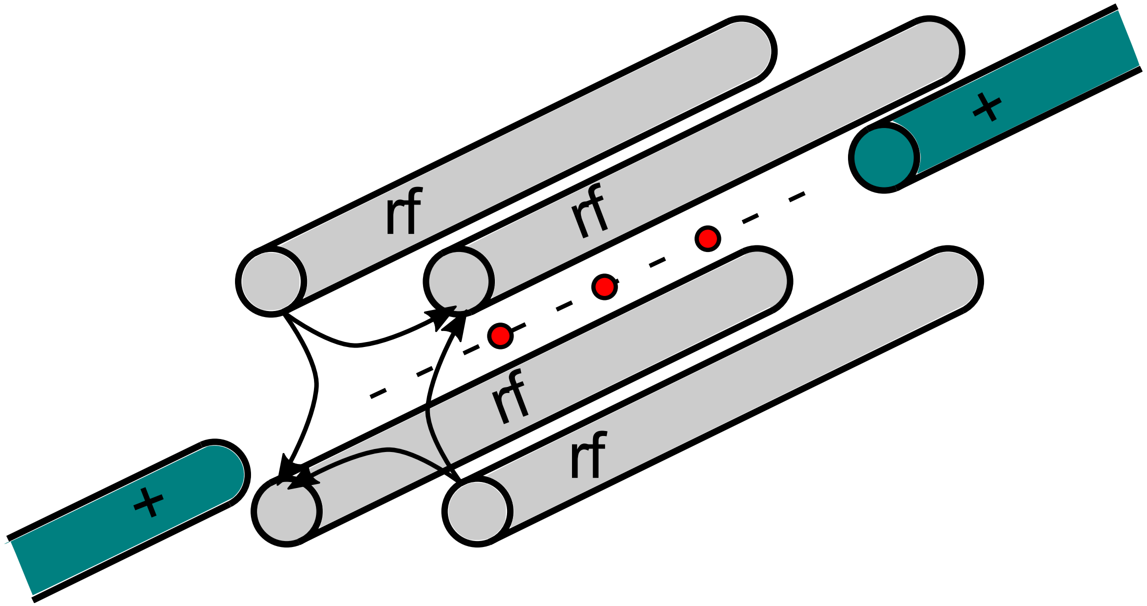
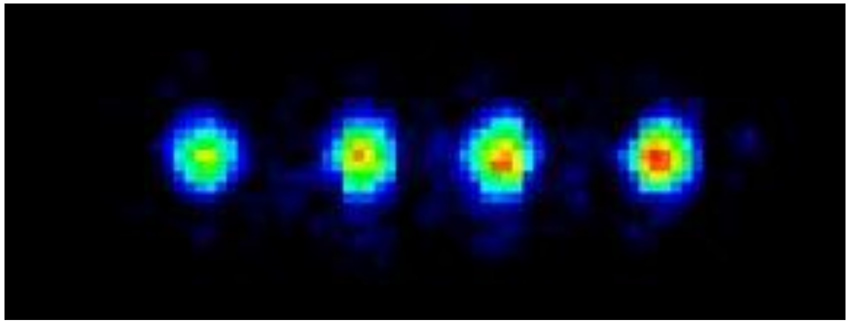
Ion trap

- A device to hold charge particles in space with electromagnetic forces

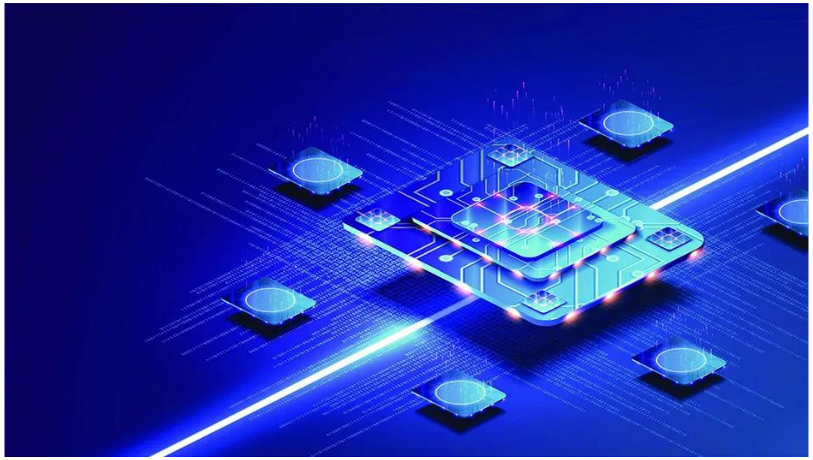


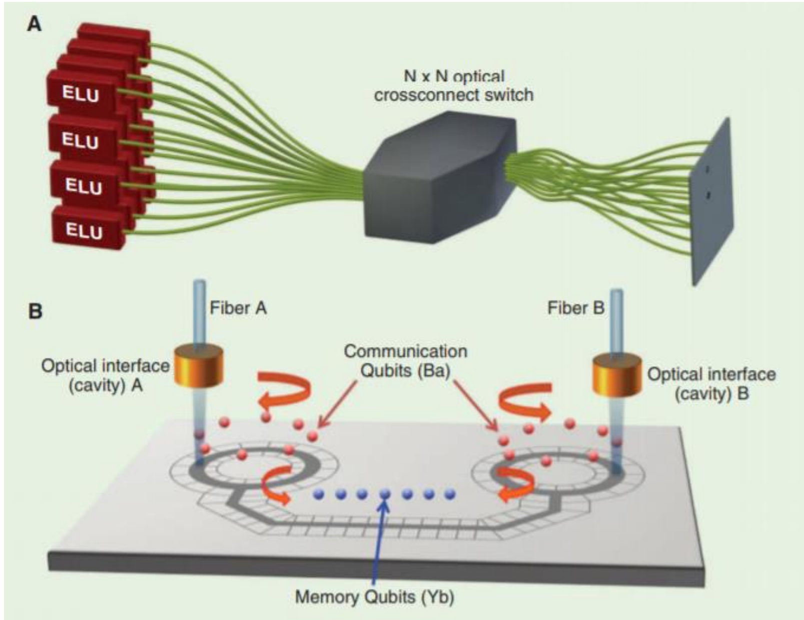


Motivation

- Ion Trap: potential quantum computer with a built-in quantum memory function

IONQ





- Photonic Interface: Composite of data readout function and networking function

Motivation

However, EFFICIENCY is problematic

Entanglement rate = 4.5 Hz **Hucul et al. Nat. Phys. 11, 37 (2015)**

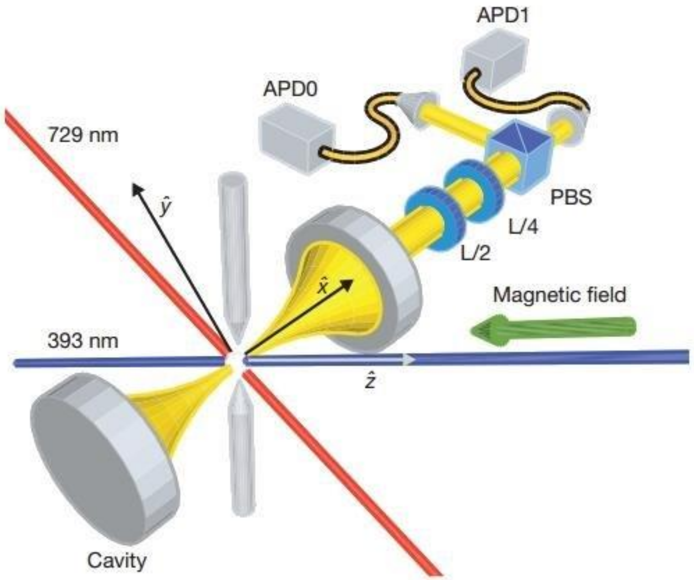
Entanglement rate = 182 Hz **Stephenson et al. Phys. Rev. Lett. 124, 110501 (2020)**

Typical Telecommunication speed

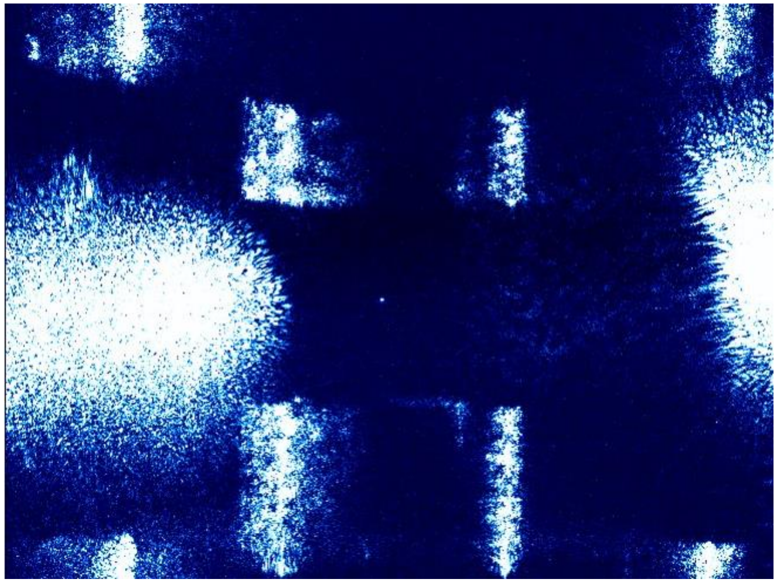
Motivation

Thus, essential to build an efficient photonic interface

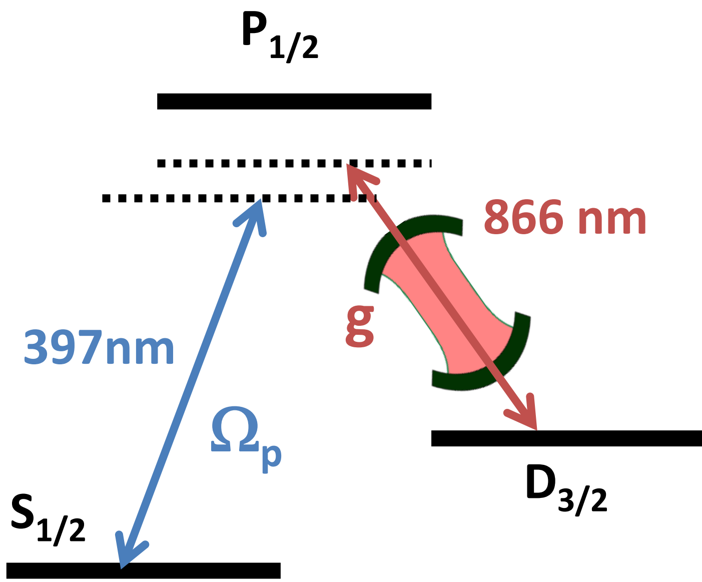
Cavity enhanced interaction and collection becomes a strong candidate



Stute *et al.*, *Nature* **485,** 482 (2012).

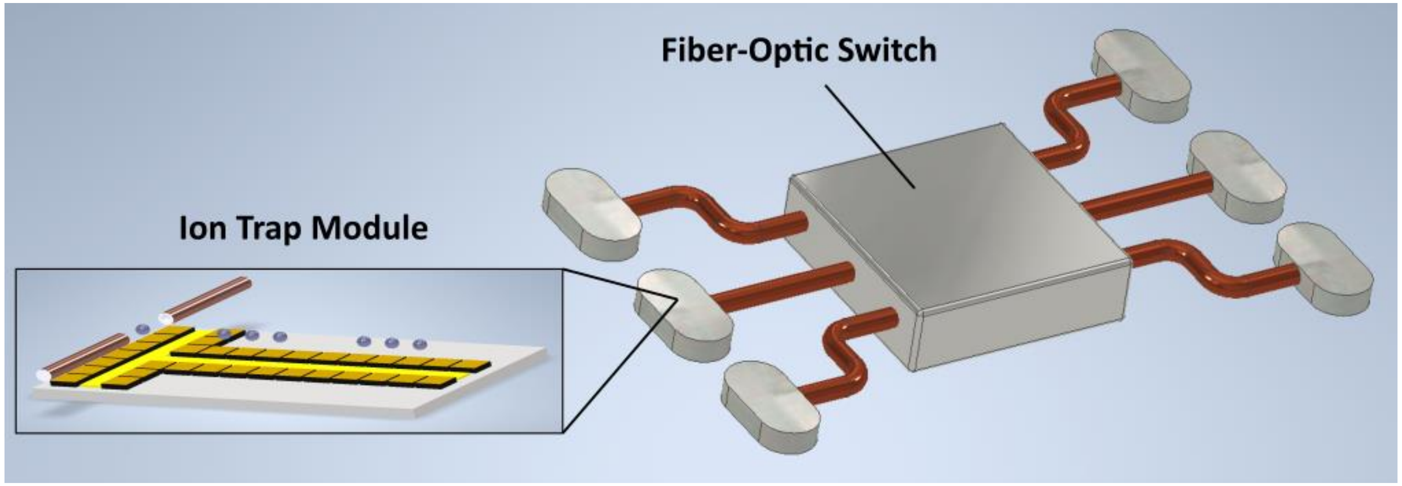


Takahashi *et al.*, *PRL* **124,** 013602 (2020).



d mirror = 0.37 mm
g = $2\pi \times 15.1MHz$
γ = $2\pi \times 10MHz$

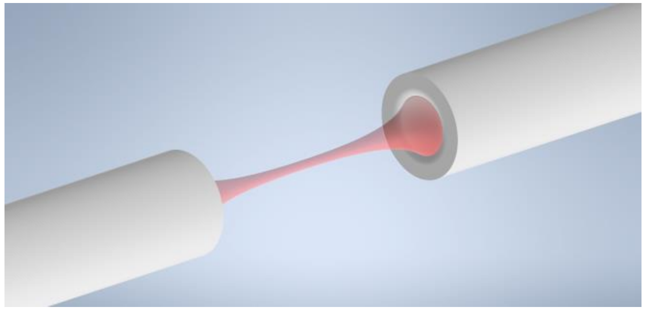
Goal



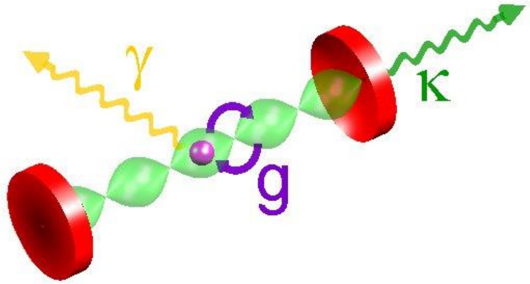
Short-term:

- Stable trapping with the existence of fibre cavity
- Coherent control on trapped ions
- Strong coupling regime on homemade 3D linear ion trap

Why Fibre Cavity

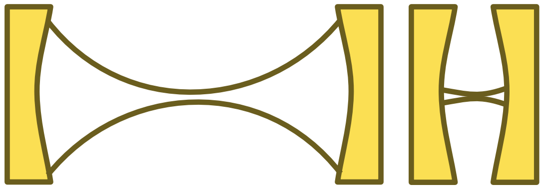


- Small mode volume



- Small region exposed to the trapped ions

- Low clipping loss



- Less loss than having external fibre coupling

$$g = \sqrt{\frac{3c\lambda^2\gamma}{4\pi V_{\mathrm{mode}}}} \propto \frac{1}{\sqrt{V_{\mathrm{mode}}}}$$

$$C = \frac{g^2}{2\kappa\gamma} \propto \frac{F}{w^2}$$

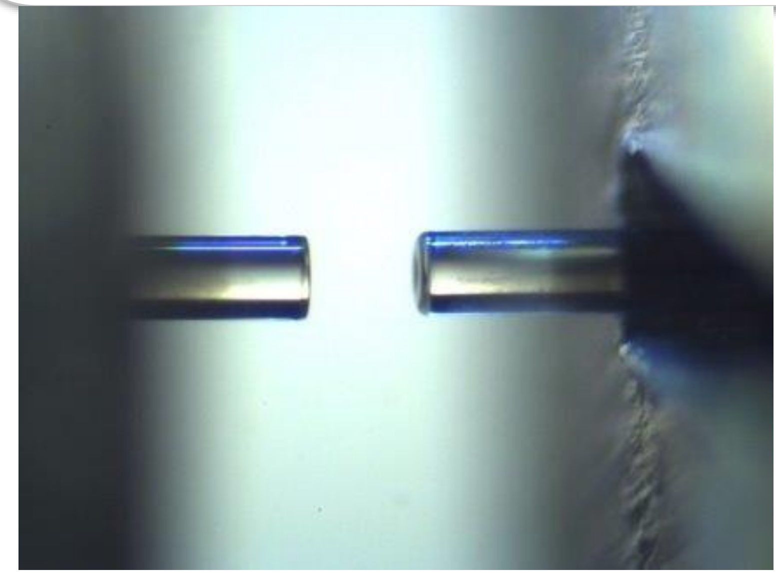
$$V_{\mathrm{mode}} = \frac{\pi\omega^2 L}{4}$$

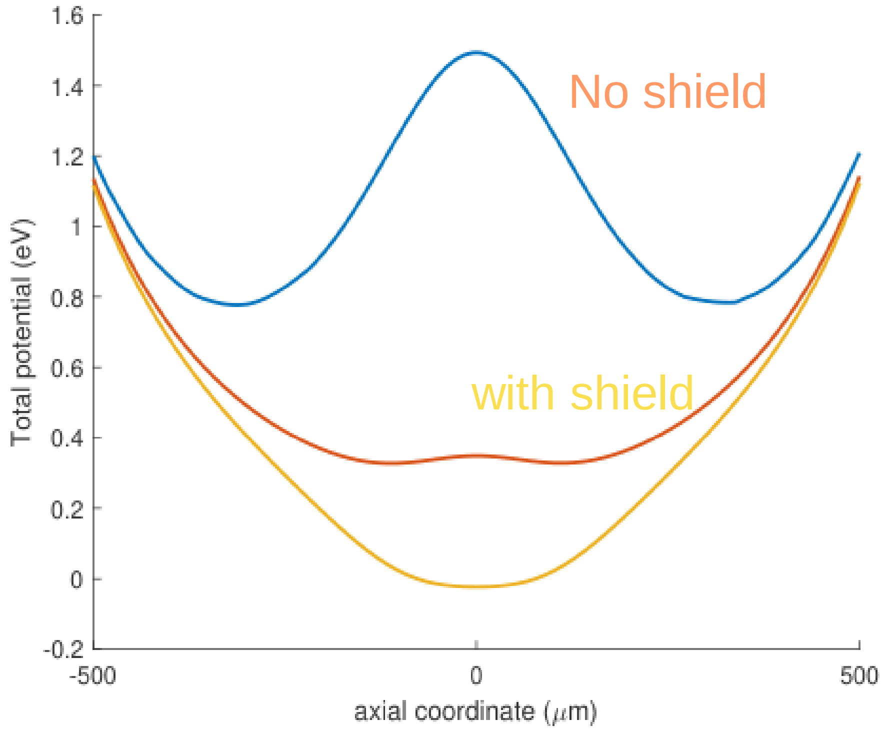
L : cavity length
F : cavity finesse
ω : waist size

Challenge from fibre cavity

Dilemma:

- Cavity QED → Short cavity preferred
- Ion trap → Long cavity preferred

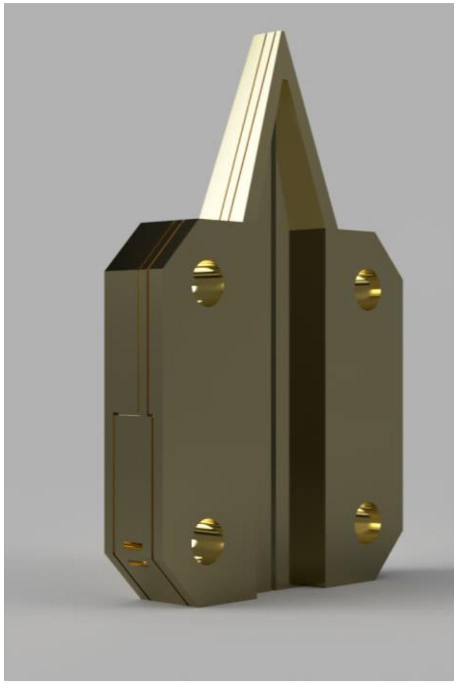


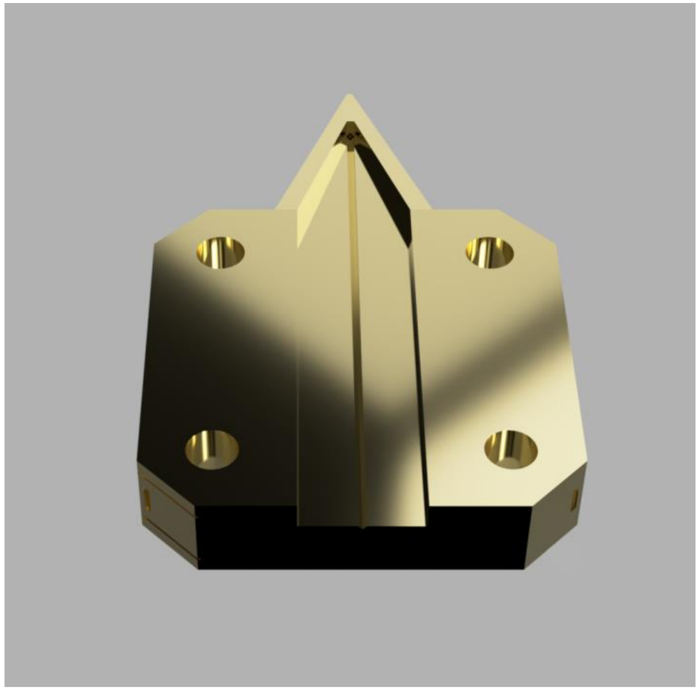


Shielding needed to protect the fundamental function: **Trapping**

Fibre Cavity Implementation

Pyramid (cavity substrate)



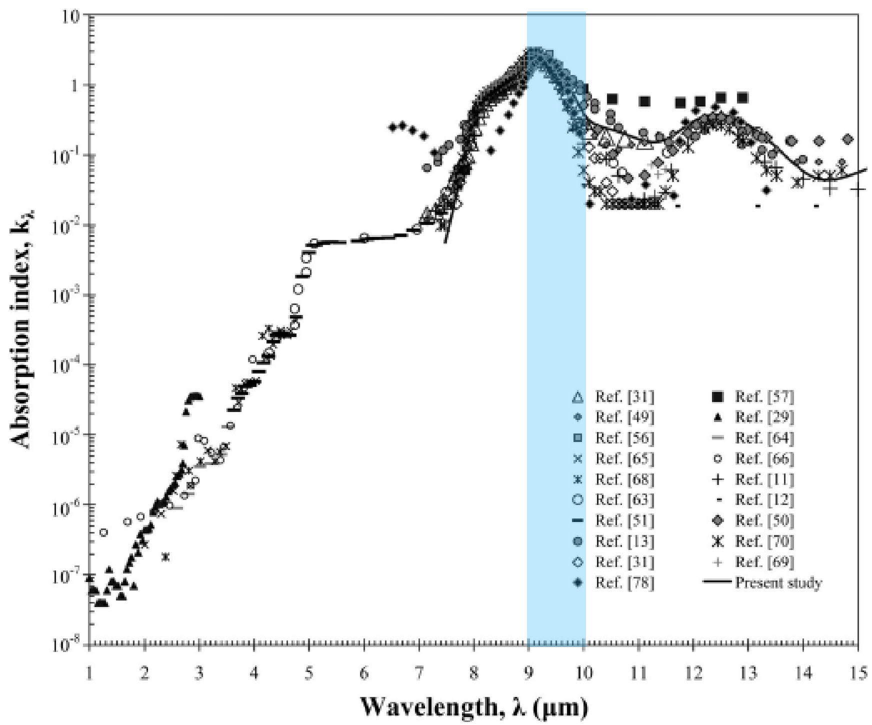


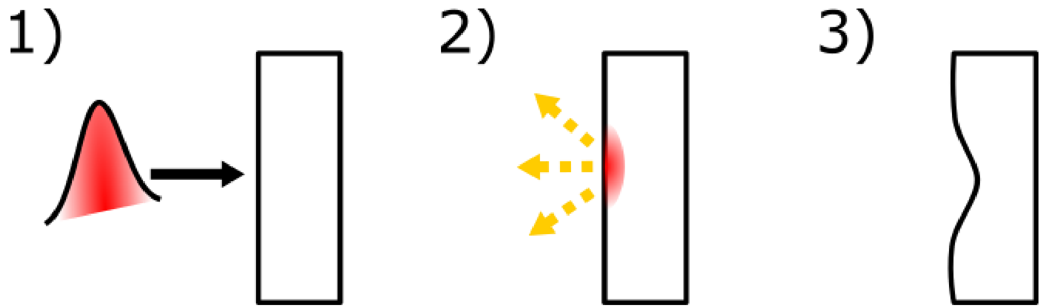
- Made by SLE and coated by gold
- Fibre inserted by nanopositioner and glued on the v-groove inside
- Mechanical stability
- Shielding the dielectrics close to trapping region

Fibre Cavity Fabrication: CO2 Laser Ablation

- CO2 Laser Wavelength: 10.6/9.3 µm

- Fused Silica Absorption spectrum:





1. Illuminate the glass substrate with a **CO2 laser pulse**.

2. Evaporation (**ablation**) and melting (**smoothing**).
   - Melting temp. at 1,900 K, evaporation at 3,000k.
   - Surface roughness ~ **0.2 nm**

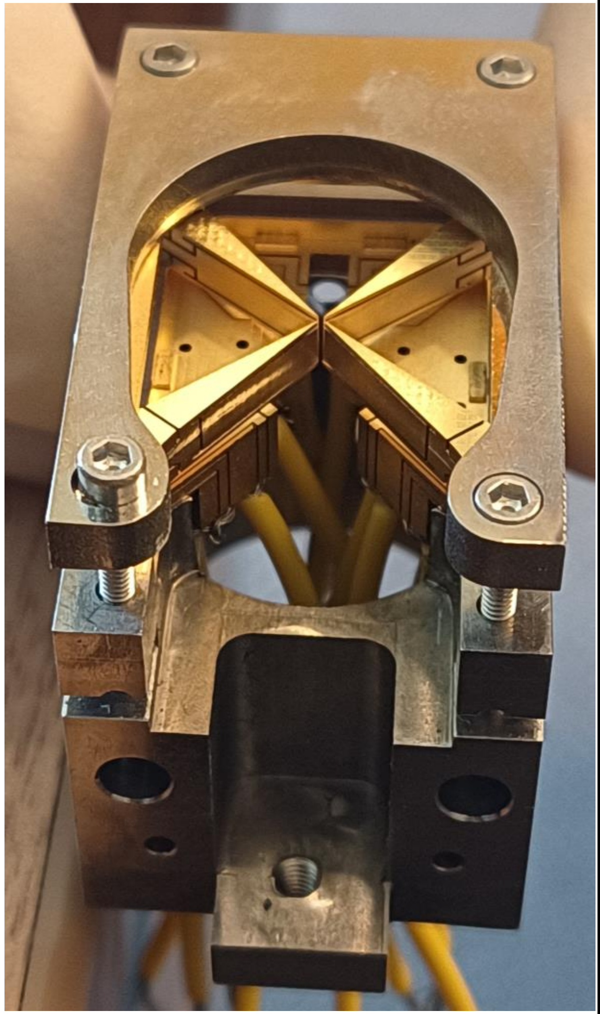
3. Depression left according to the laser intensity distribution (normally Gaussian).

Sugoi Trap 1st Generation

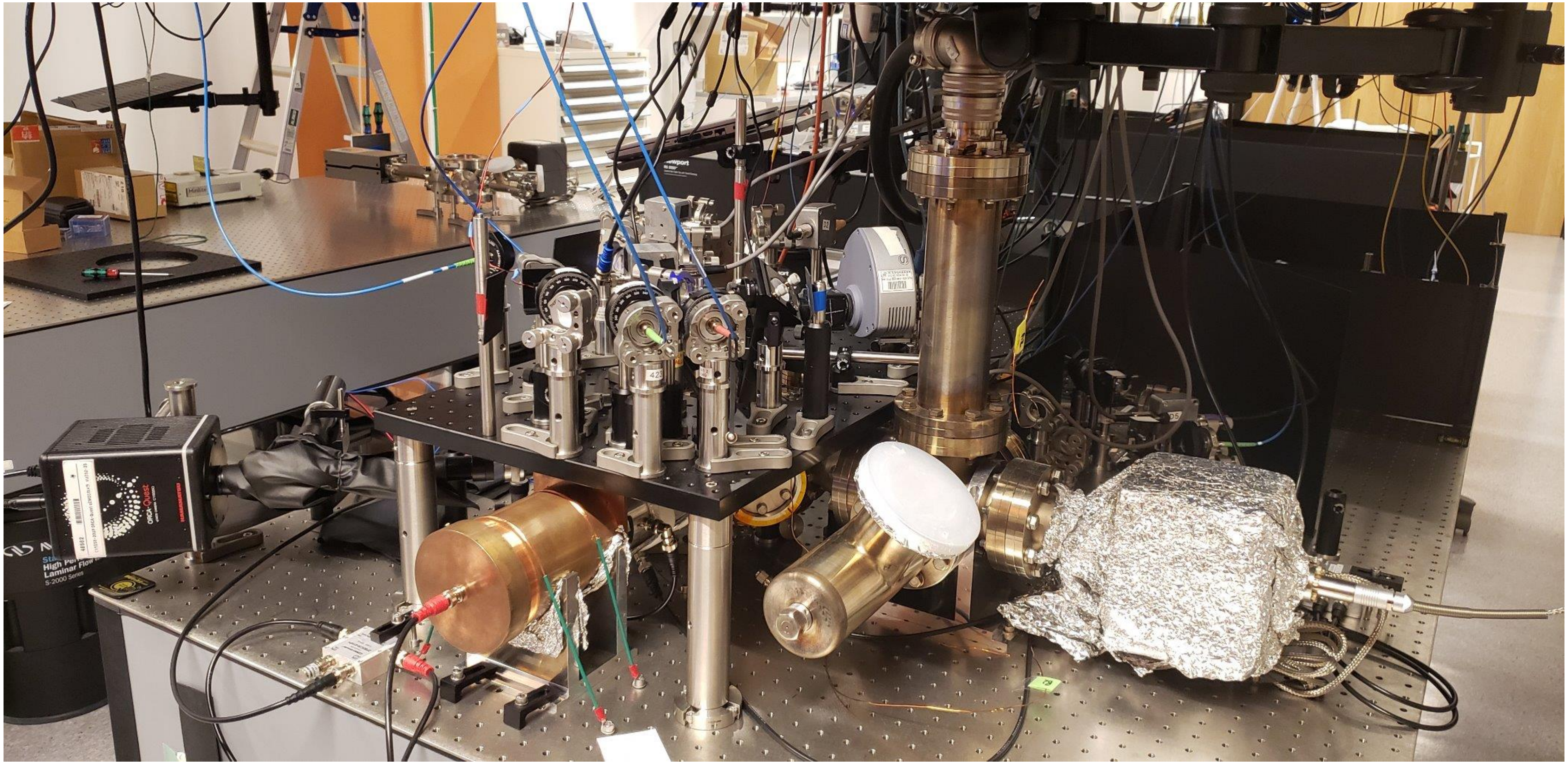
Dimension:20mm * 20mm

Made by SLE with surface roughness 100-200nm

Electrodes insulated by trenches

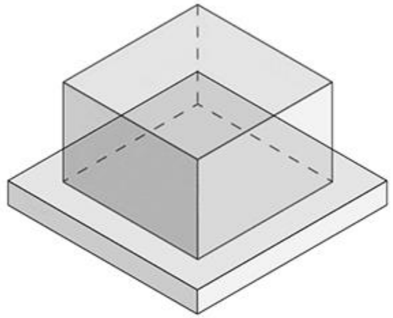


Sugoi Trap 1st Generation

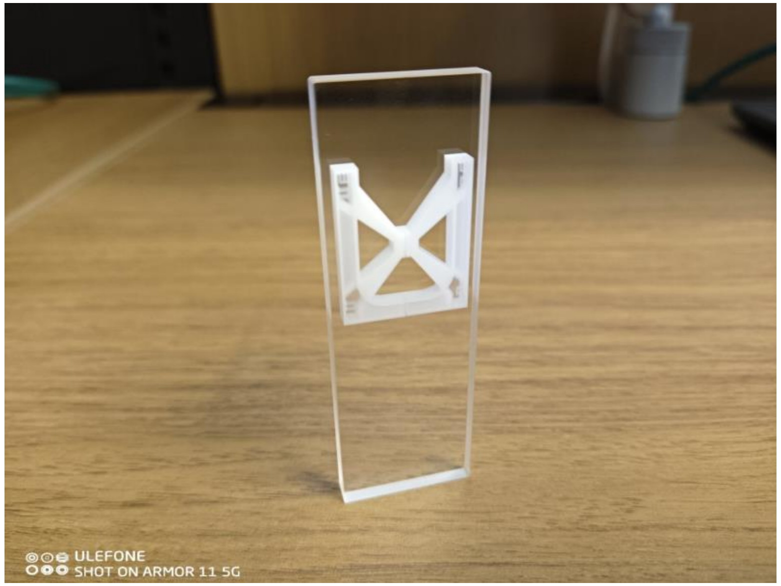


Trap Fabrication

- Selective Laser Etching
- Coated by Gold

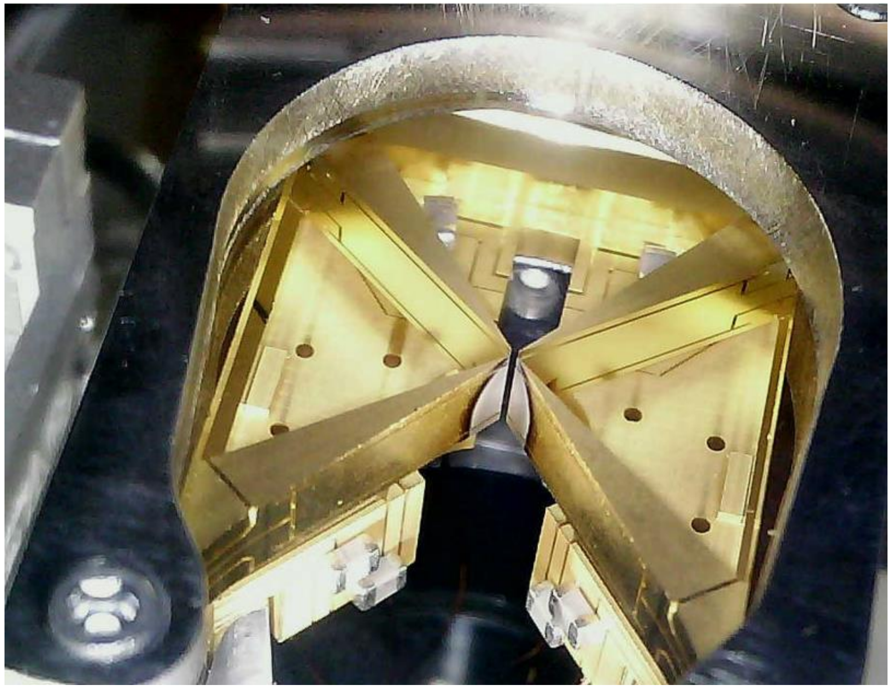


femtika



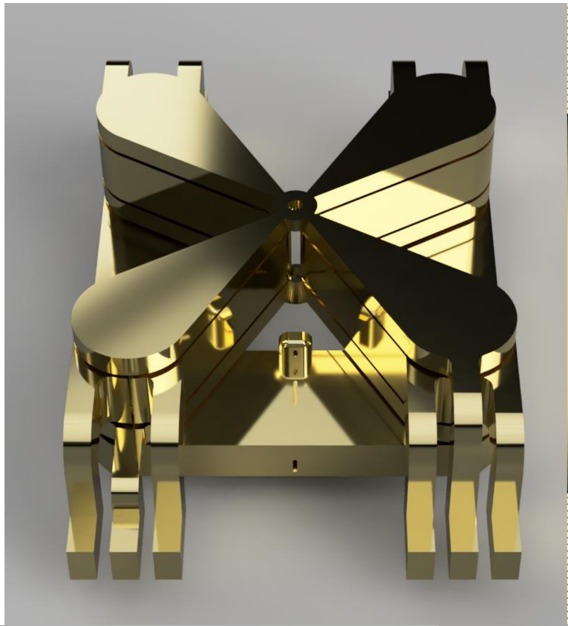
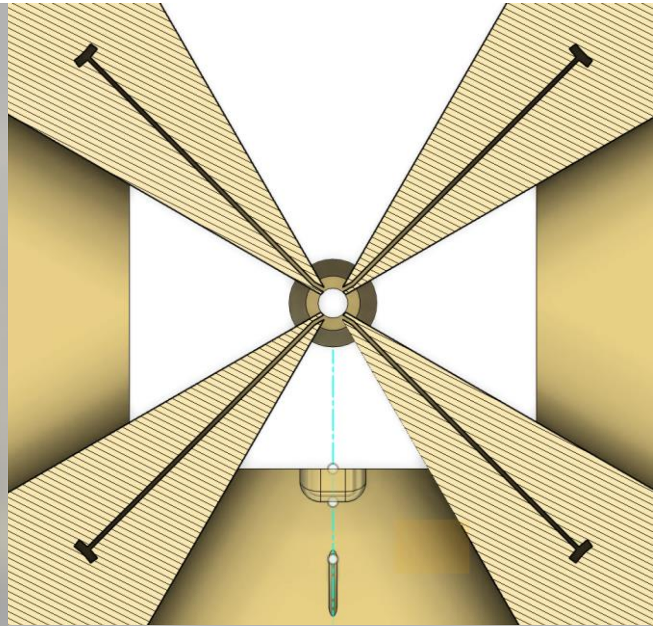
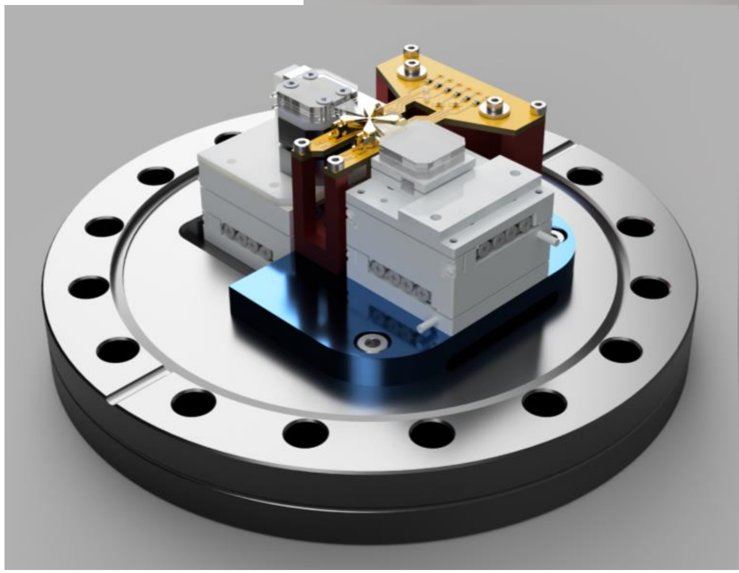
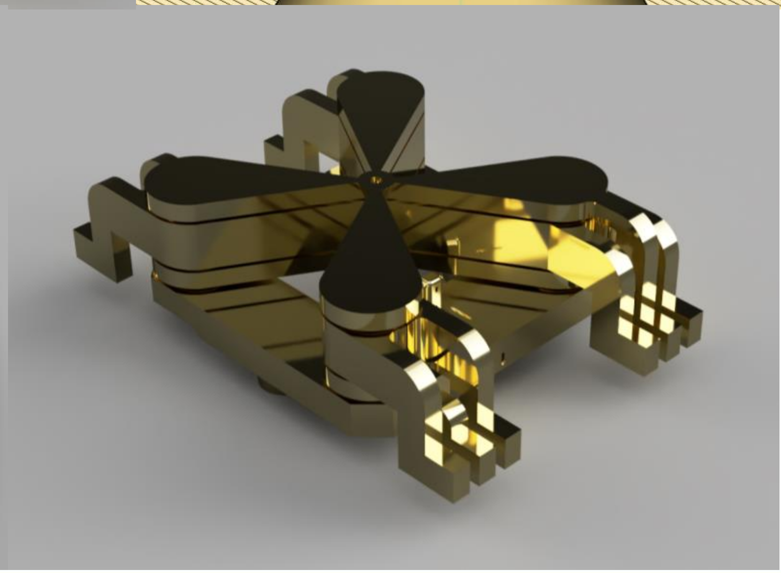
Possible Improvements

- Congested wires
- Mechanical Stability of fibre cavity substrate
- DC compensation
- Oven collimation

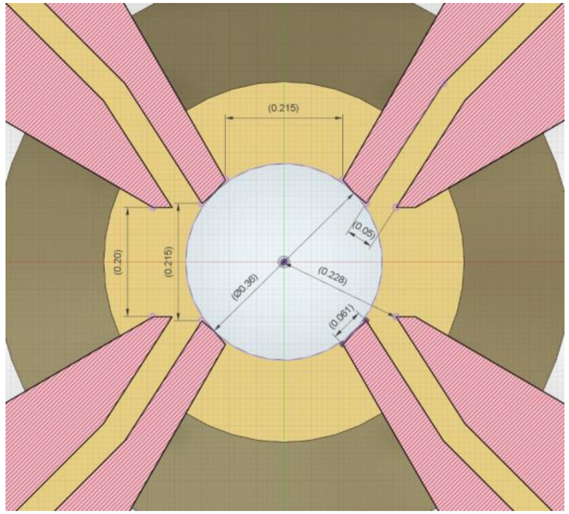


Model of Sugoi Trap 2^{nd} Generation

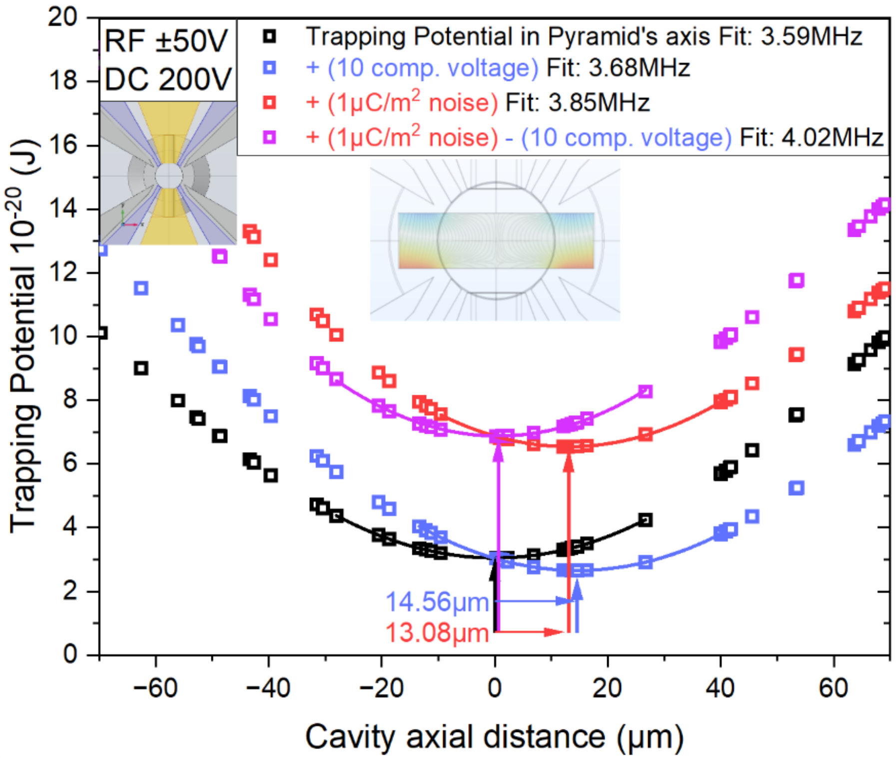
- Optically Heated Oven
- Monolithic Oven Collimator
- Ceramic PCB connected by wire bonding
- 4 RF blades + 4 DC compensation blades
- Dimension:10mm * 10mm

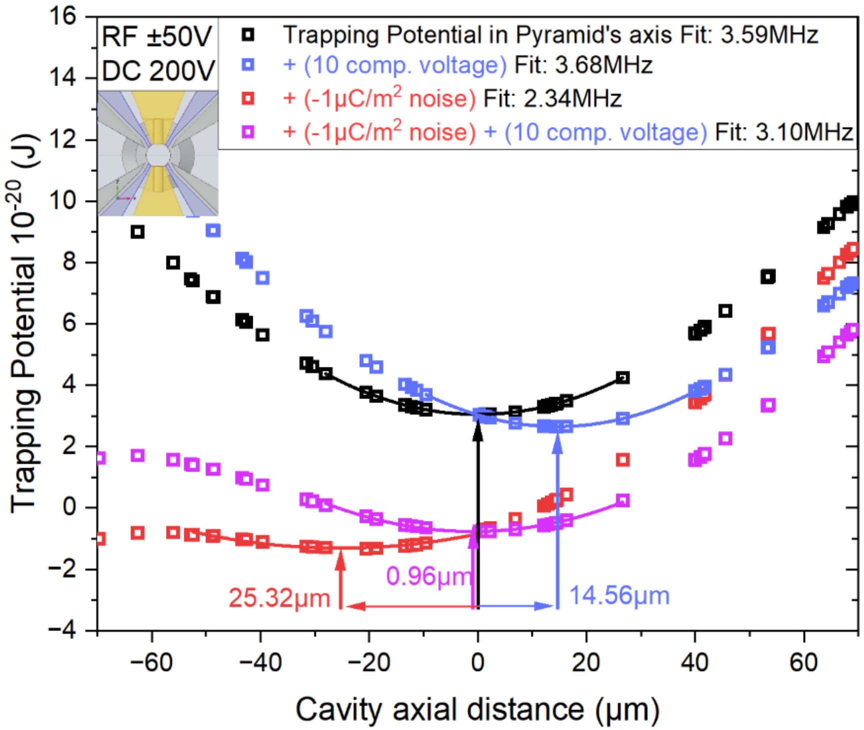





Simulation Result from 2^{nd} GEN

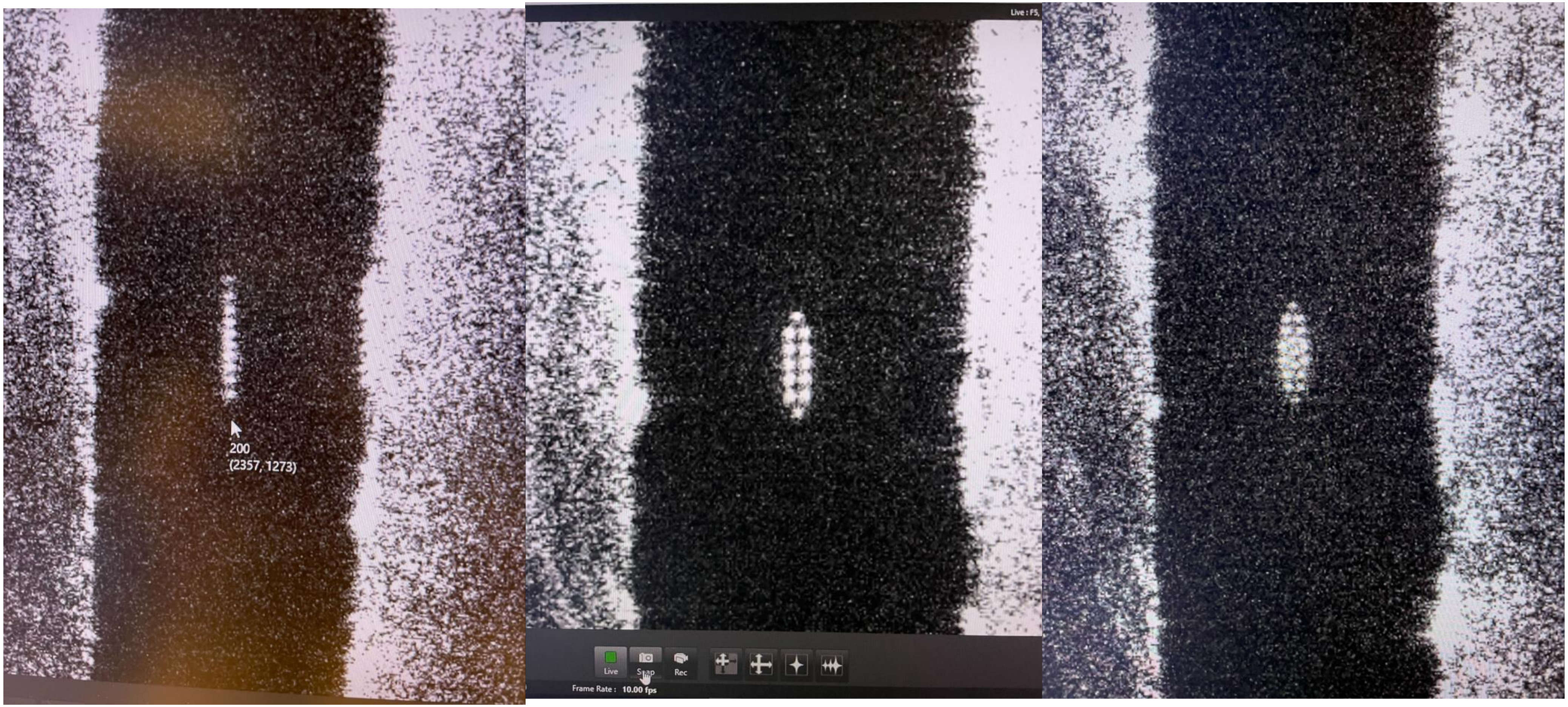


Compensation on the effects by fibre cavity





Trapping by 1st Generation Trap

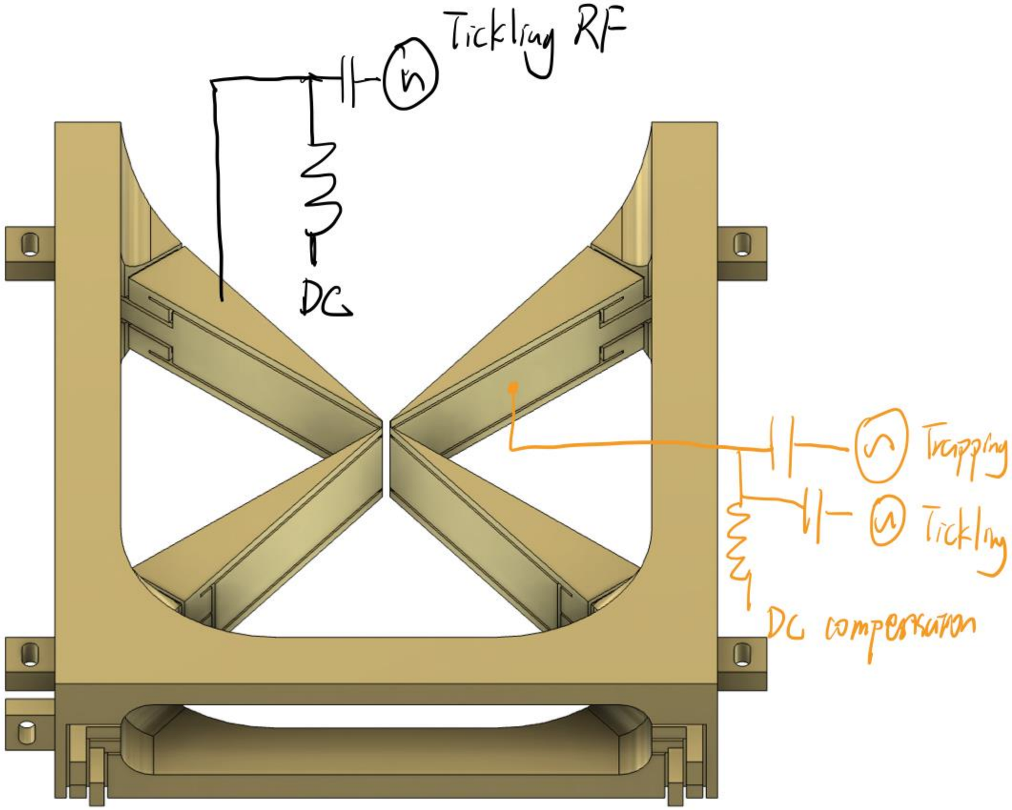


with different endcap voltage

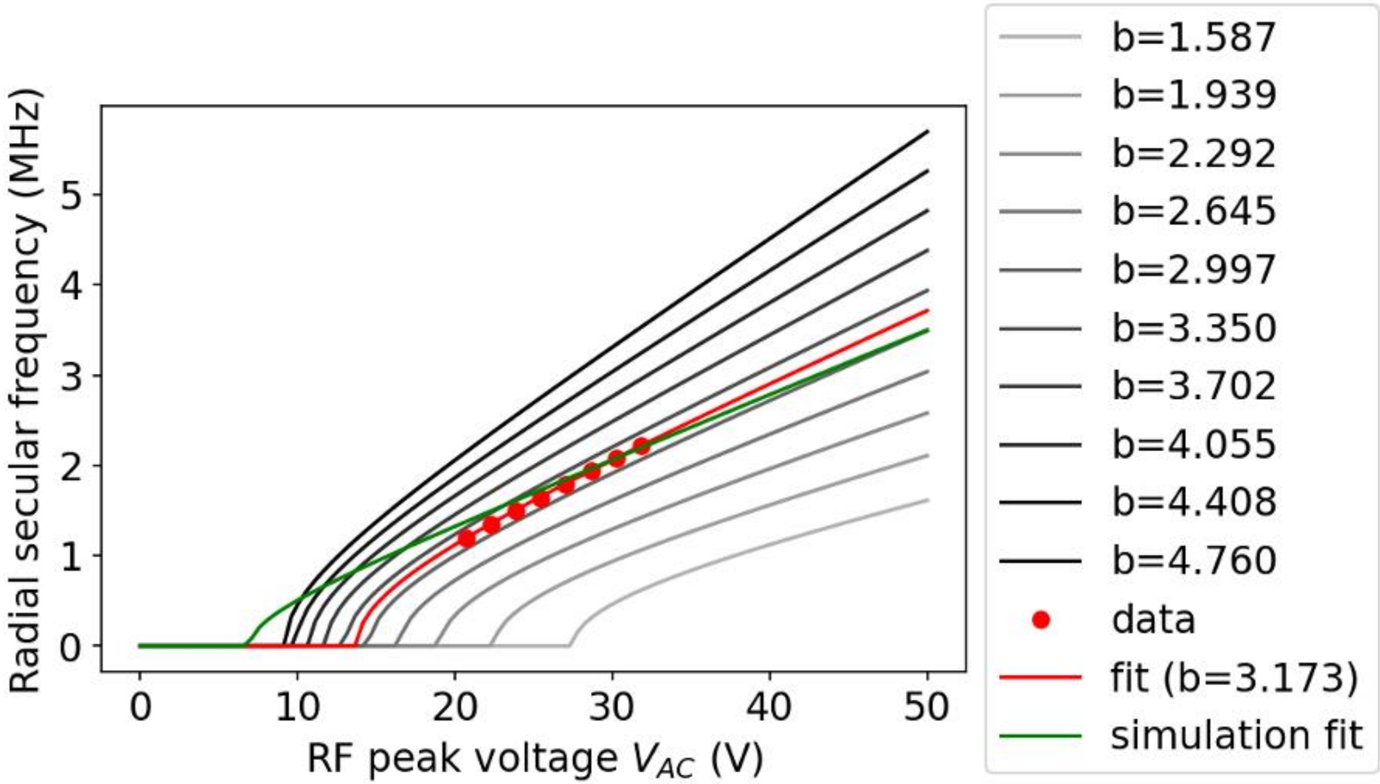
Secular Frequency Characterisation

Technique:

Excite the ions by a scanning tickling signal



Secular Frequency Characterisation

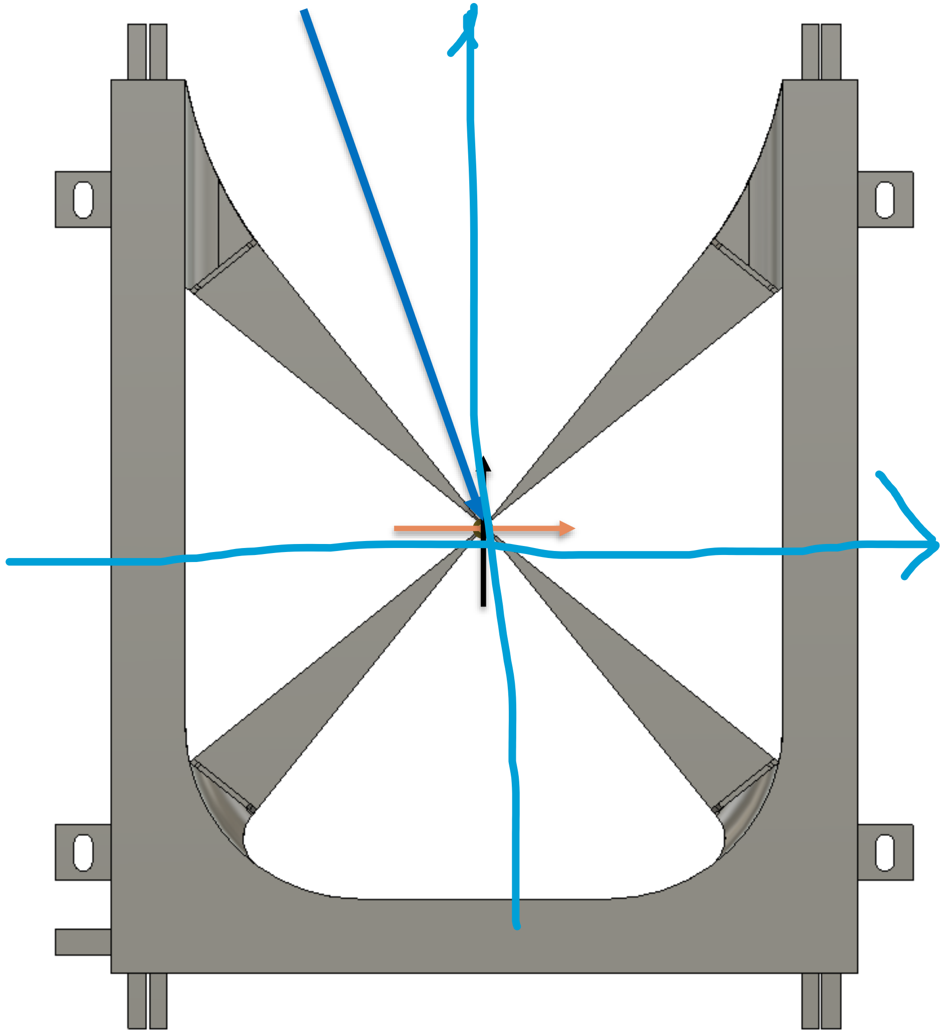


$$q = \frac{2eV}{Mr_0^2\Omega^2} \quad b = \frac{e\alpha V_{cap}}{mL^2\Omega^2} \quad \omega_r = \omega_x = \omega_y = \frac{\Omega}{2}\sqrt{\frac{1}{2}q^2 - b}$$

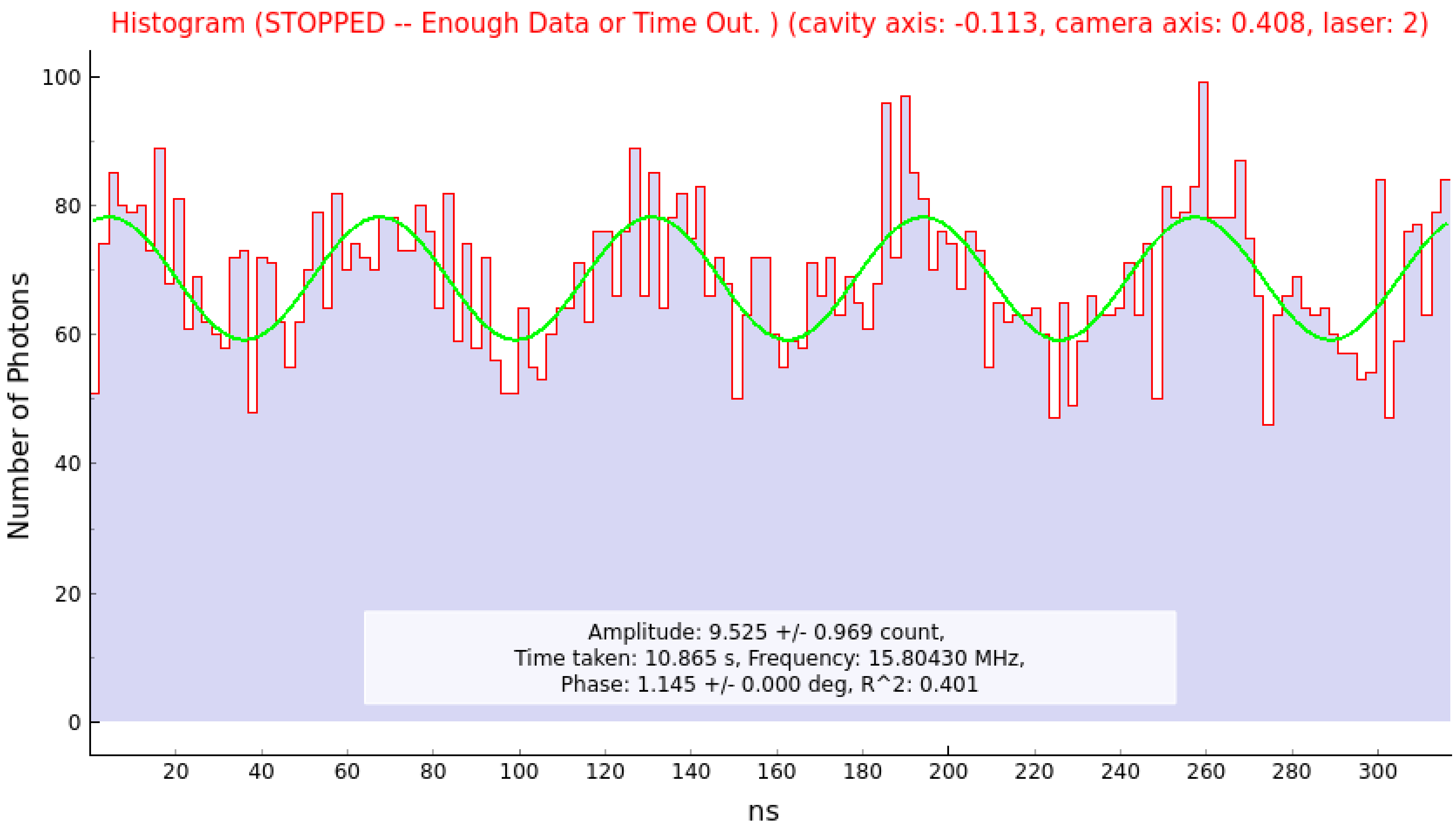
Micromotion Compensation

- Trapping position is not at the point due to stray charge, fabrication imperfection etc.

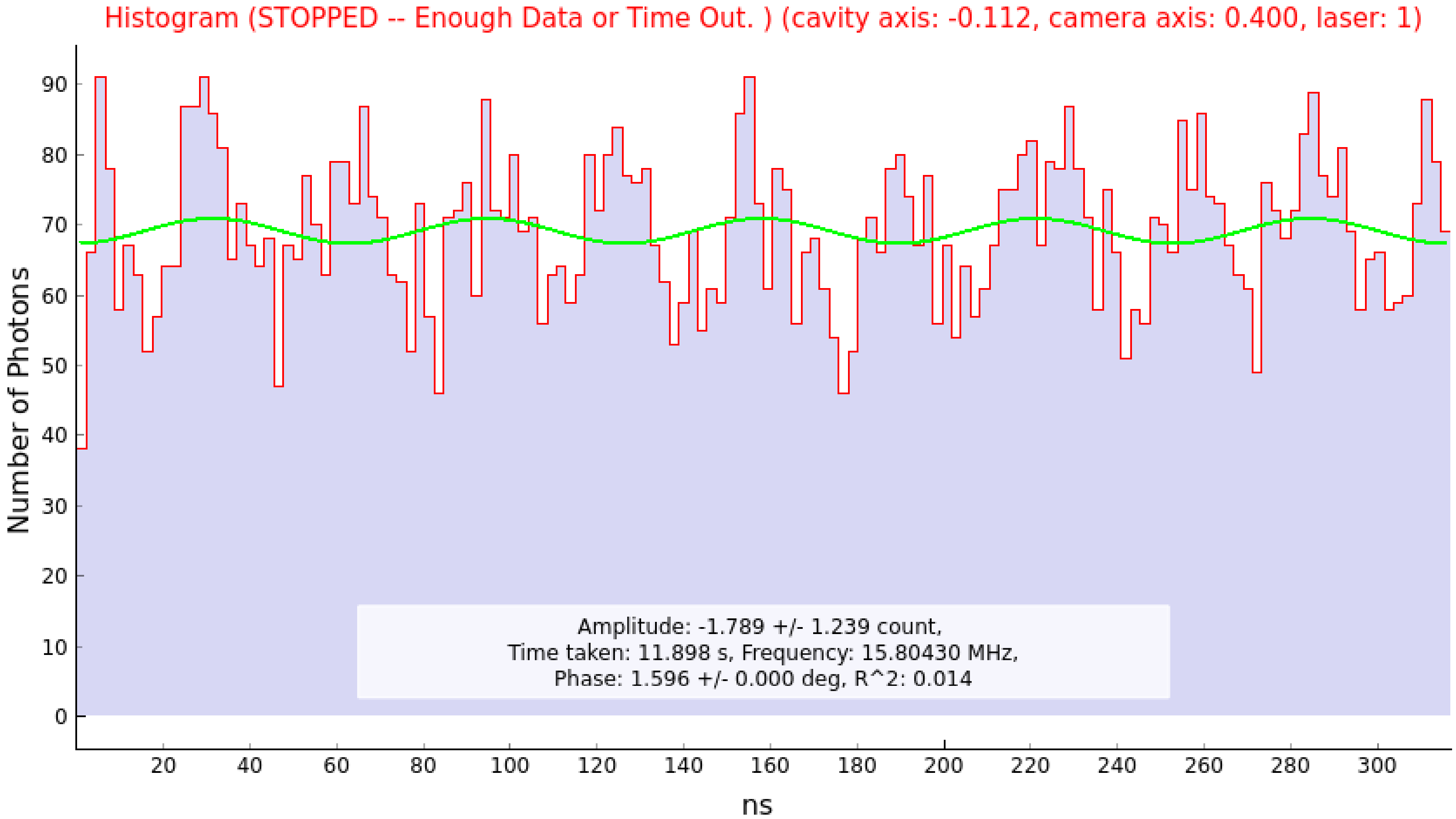
- Homemade micromotion detector by PMT and FPGA and two 397 laser beams to monitor the micromotion of trapped ions



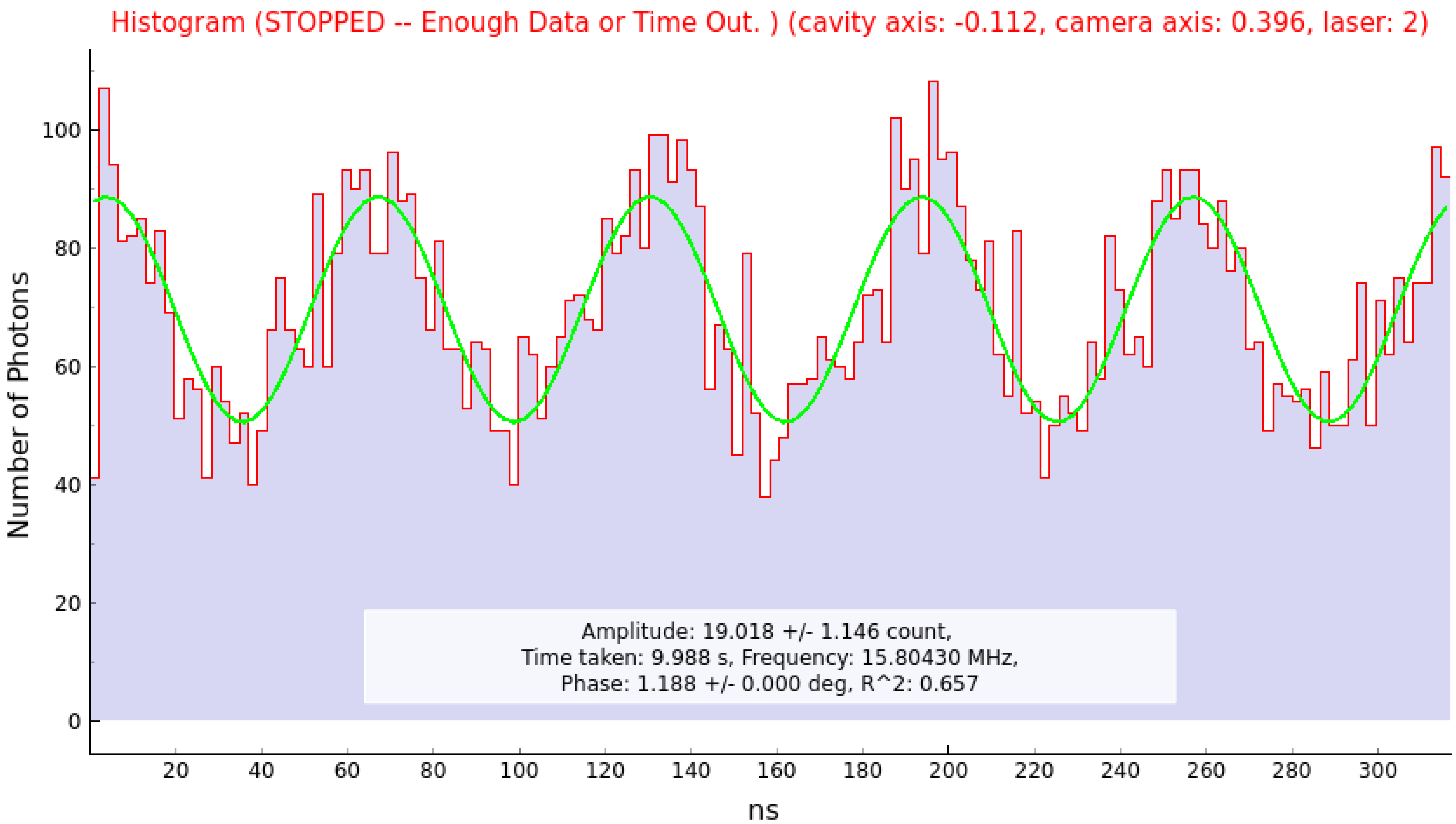
Micromotion Compensation



Micromotion Compensation



Micromotion Compensation



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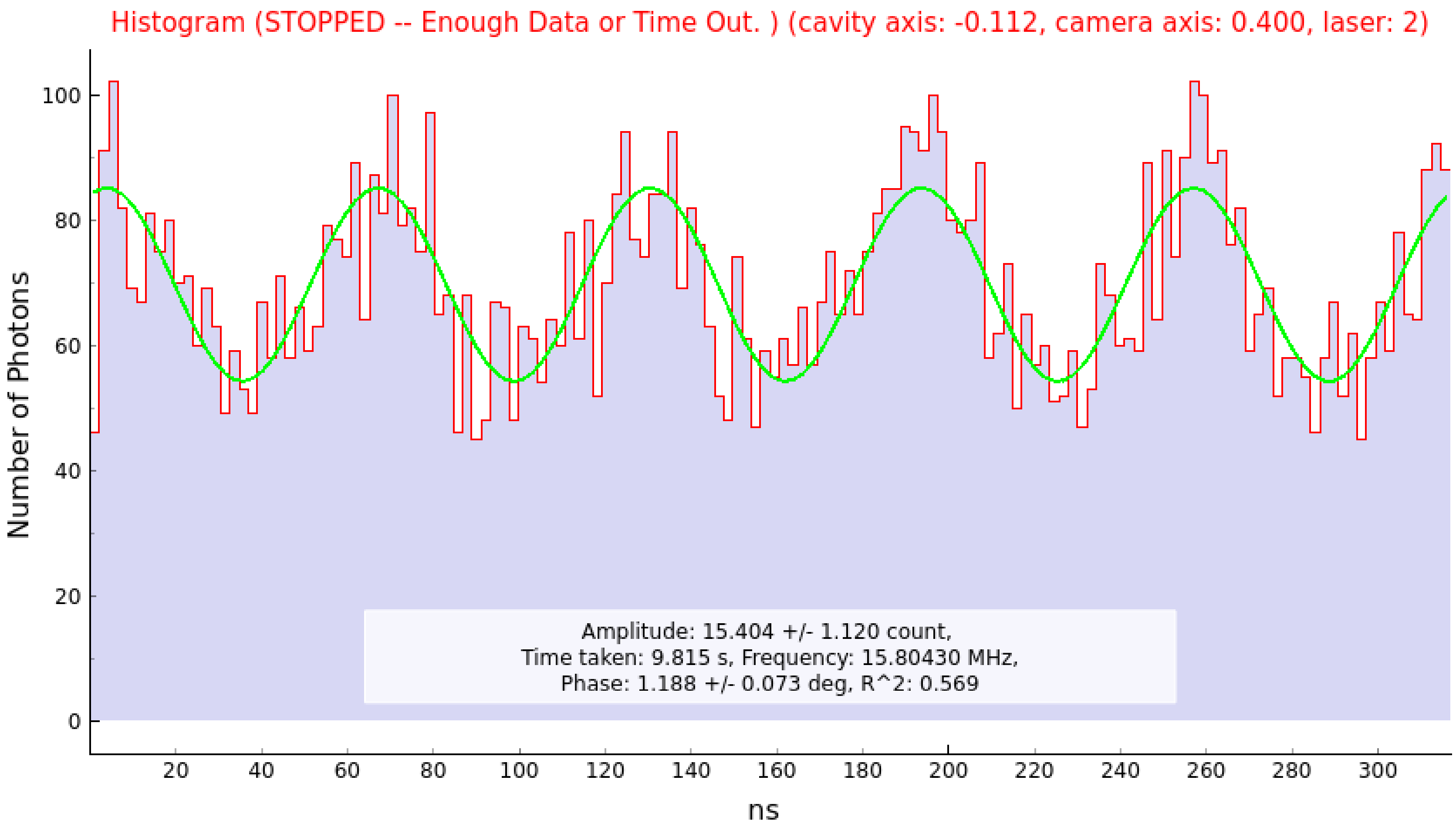

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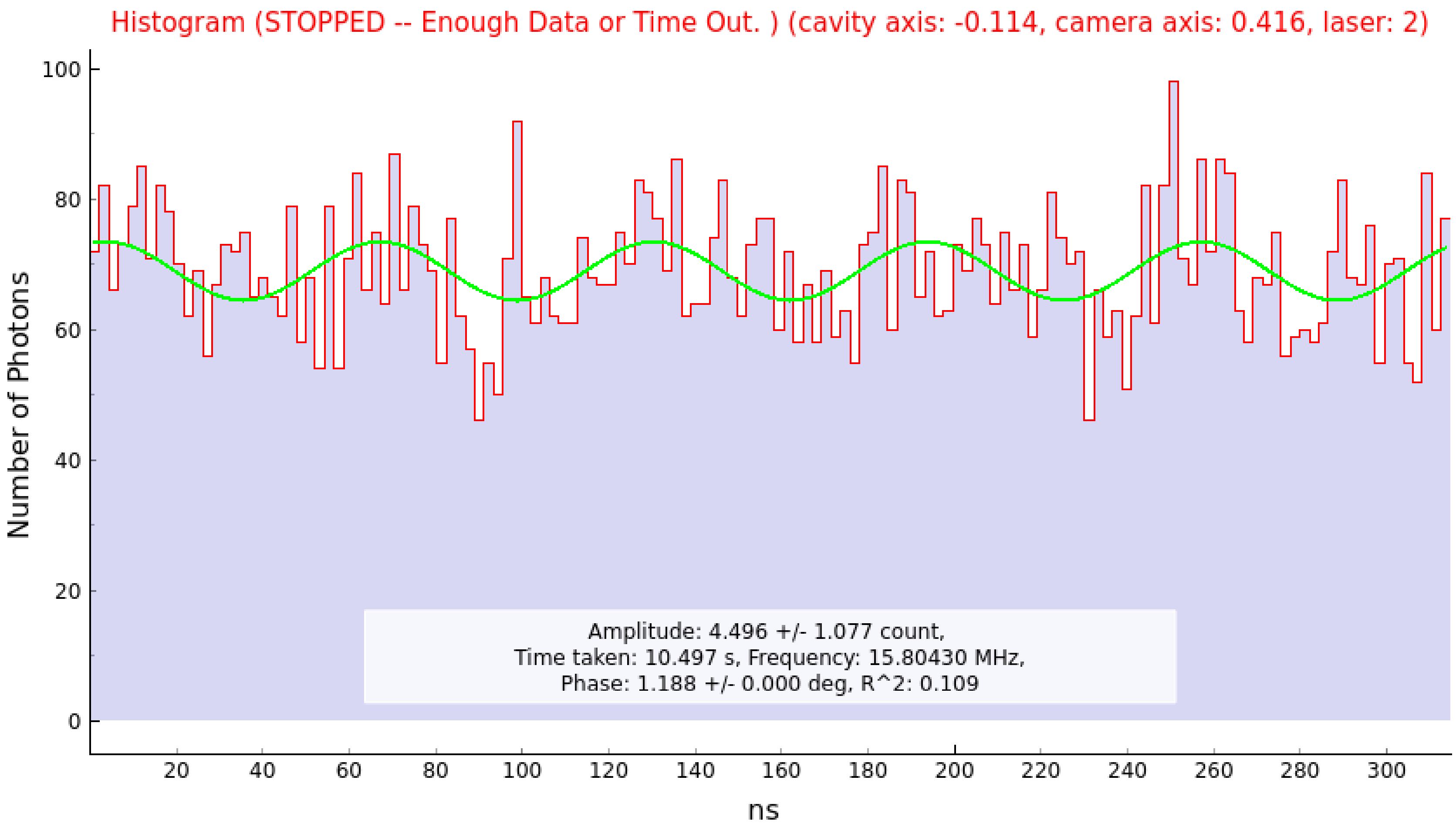
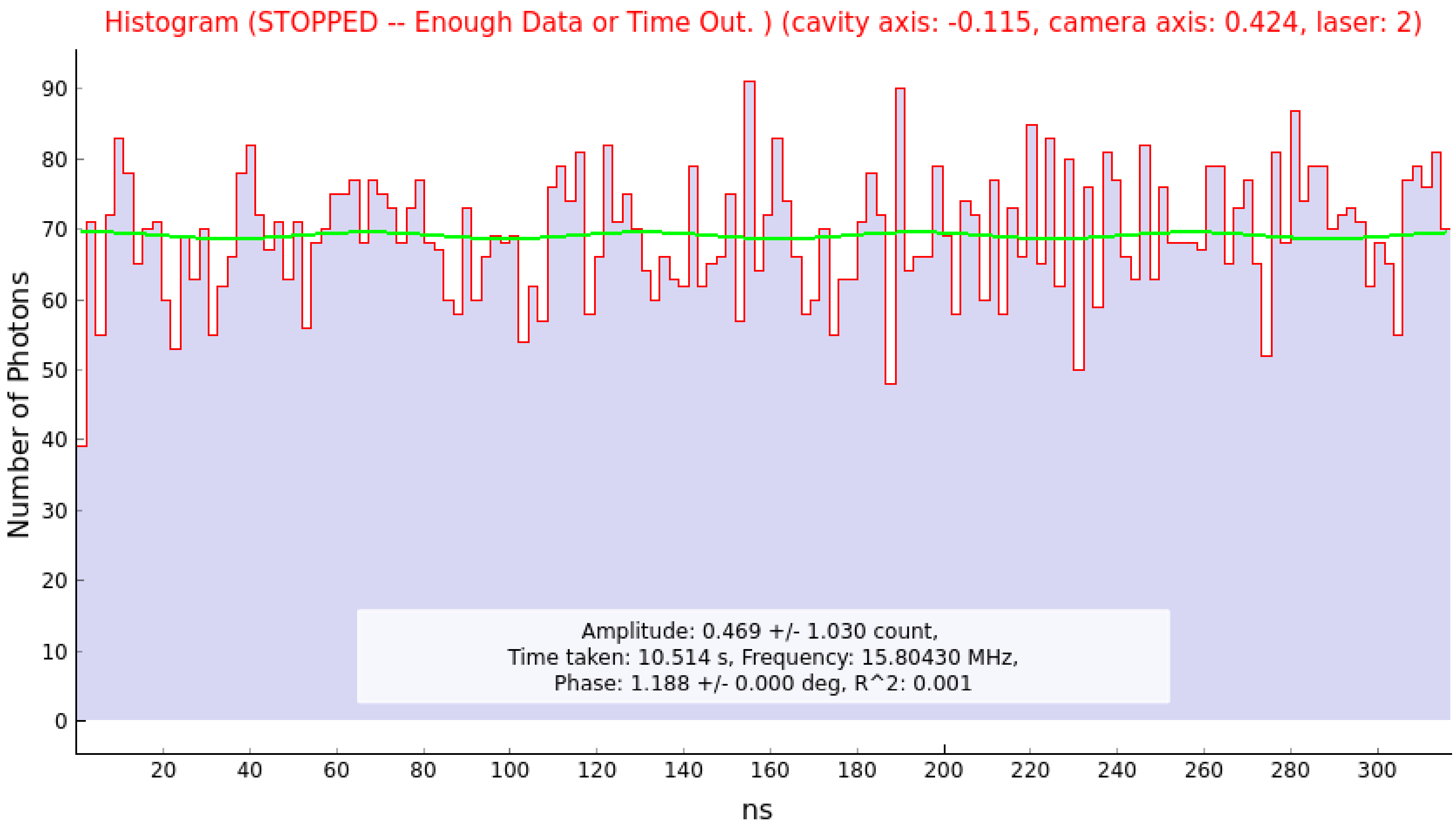
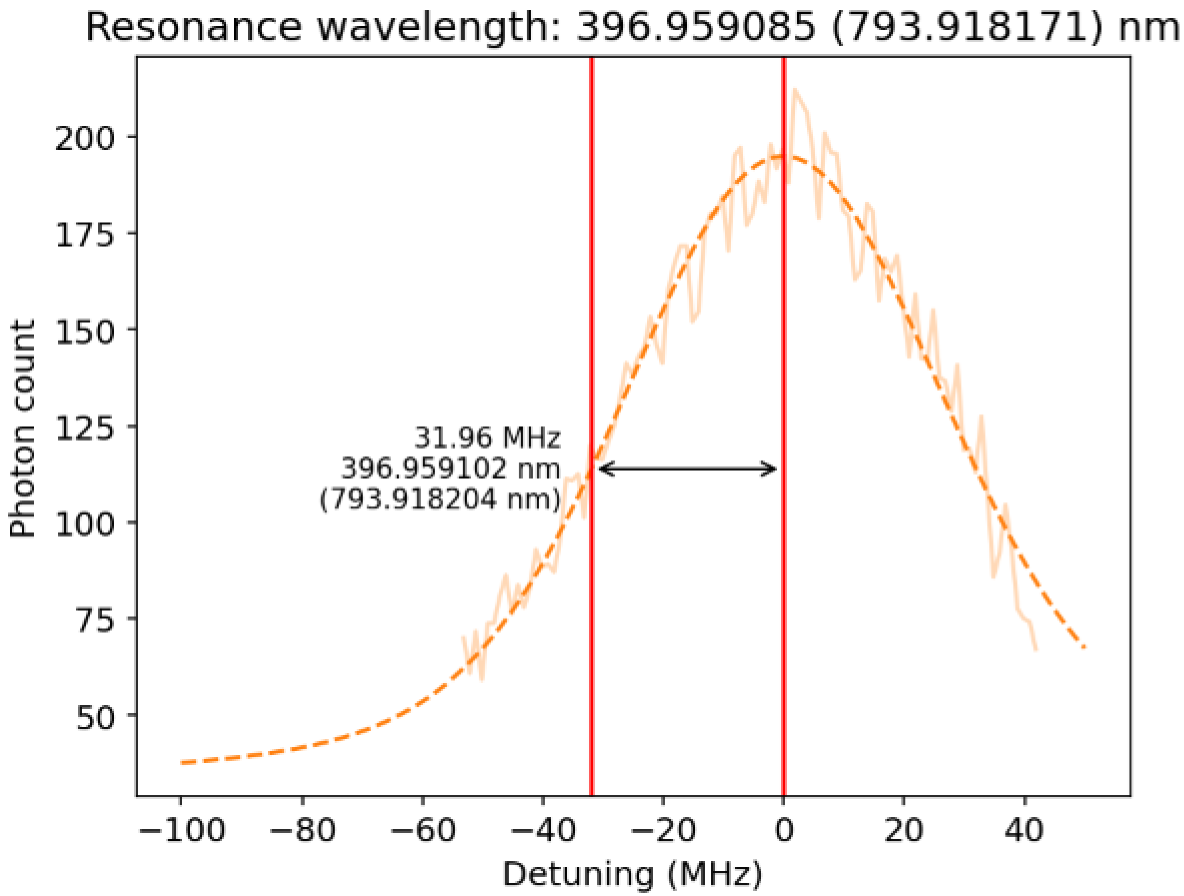


Micromotion Compensation



397nm Spectrum

- Somehow broader than the natural transition linewidth



Conclusion and Outlook

Things Done:

- Trapped with miniaturized monolithic 3-D linear trap
- Fabricated our own fibre cavity mirrors
- Designed the further miniaturized 2 GEN trap

Things to be done:

- Couple the fibre cavity to ions in linear trap
- Cavity-enhanced communication between distant nodes
- Interface between superconducting and ion trap system

Thanks for your audience

OIST

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