An efficient method of tuning plasma haloscopes with spirals and concentric rings

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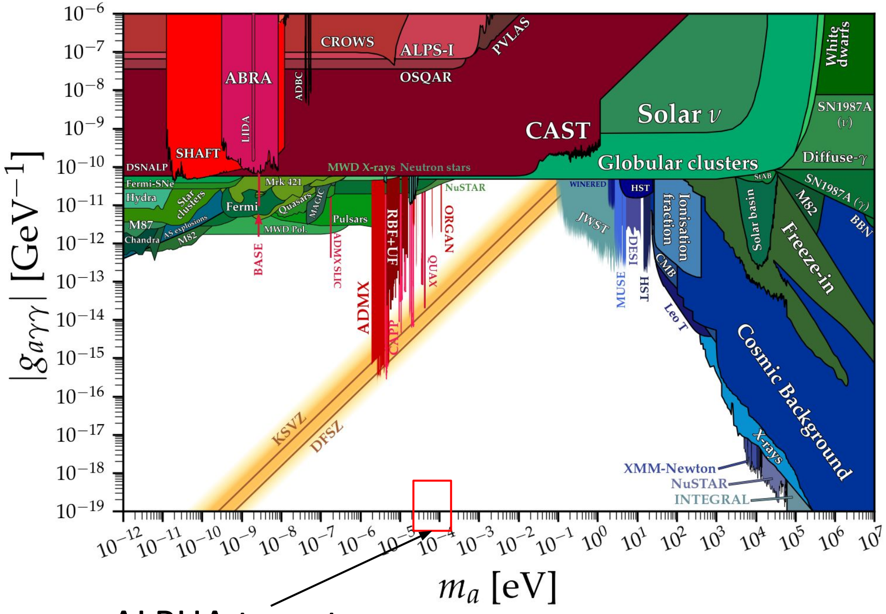
Stockholm University for IDM 2026
June 4th, 2026

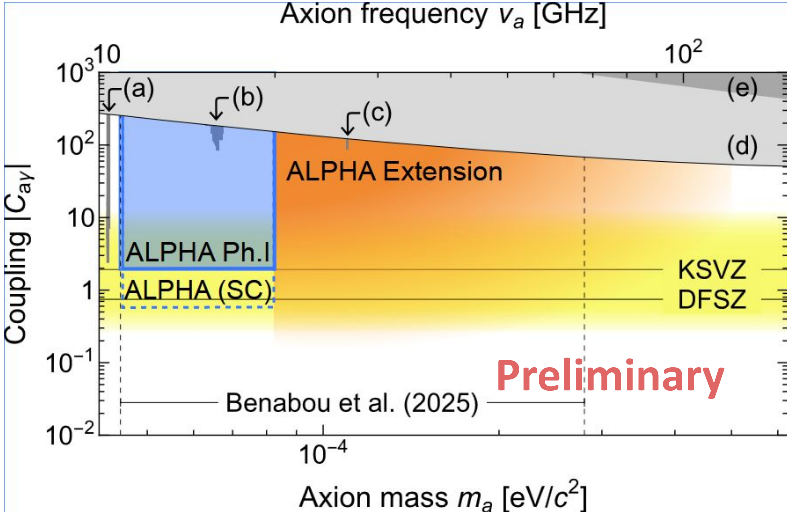
Obligatory axion slide

Ciaran O Hare limits

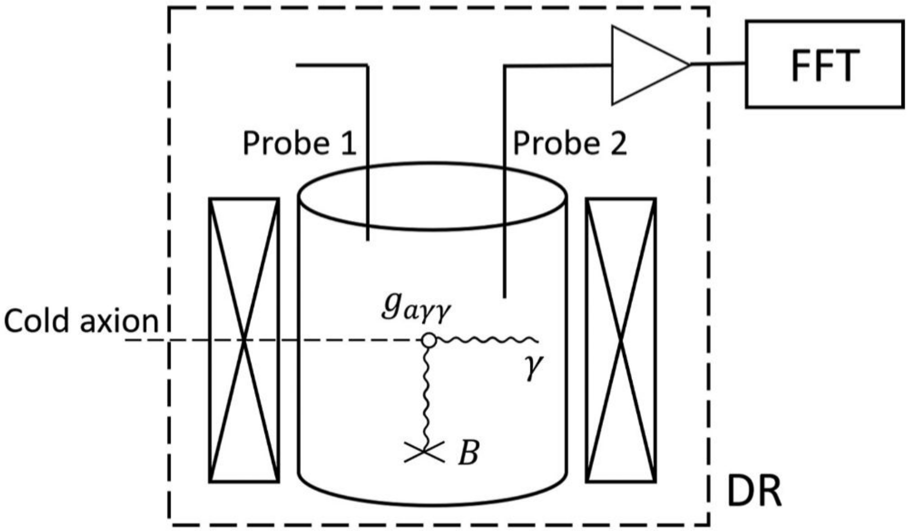


ALPHA target mass range

- Simulations place (post-inflationary) axion mass of several 10s of μeV
- Few μeV region has good coverage, what about higher masses?



The problem with higher masses



H. Chang. Rev. Sci. Instrum. 93, 084501 (2022)

- Axion interacts with a magnetic field to convert to real photons
- Real photons excite a resonance inside of a cavity
- Mode of interest: TM_{010}

The problem with higher masses

$$\frac{df}{dt} = g_{a\gamma\gamma}^4 \frac{\rho_a^2}{m_a^2} \frac{1}{\mathrm{SNR}^2} \frac{B_0^4 \boxed{V^2 C^2}}{k_B^2 T_{\mathrm{sys}}^2} \frac{\beta^2}{(1+\beta)^2} Q_a \min(\boxed{Q_l}, Q_a)$$

Controllable by cavity design

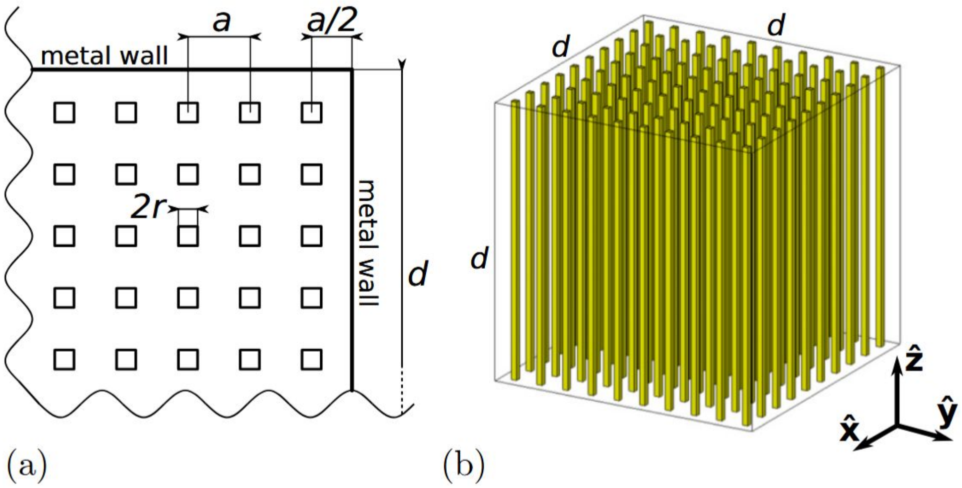
- V = volume
- C = form factor (coupling of E to external B)
- Q = quality factor (proxy for losses)

$$\boxed{f_{010} = \frac{c}{2\pi} \frac{j_{01}}{R}}$$

(for an empty cavity)

Higher mass ⇒ higher frequency ⇒ smaller volume ⇒ ***slower scan speed***

The ALPHA experiment and plasma haloscopes



R. Balafendiev et al. Phys. Rev. B ***106****, 075106*

$$\boxed{k_p^2 = \frac{2\pi/a^2}{\ln\frac{a}{2\pi r} + F(1)}}$$

(for the cavity shown above)

- ❖ Wire grid decouples frequency from volume by using an array of wires
- ❖ Large volume, high frequency!
- ❖ Trade off: lower quality factor (Q)
  - ➢ Scan rate is only linear with Q
  - ➢ Can be improved with superconducting wires
- ❖ ALPHA: **A**xion **L**ongitudinal **P**lasma **HA**loscope

ALPHA Collaboration

2025 ALPHA Collaboration Meeting

alpha

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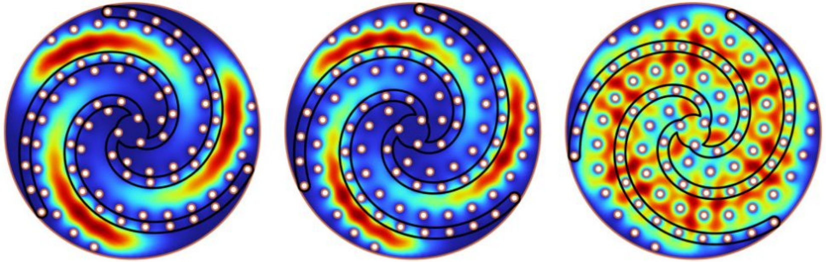
Knut and Alice Wallenberg Foundation

Simons Foundation

Swedish Research Council

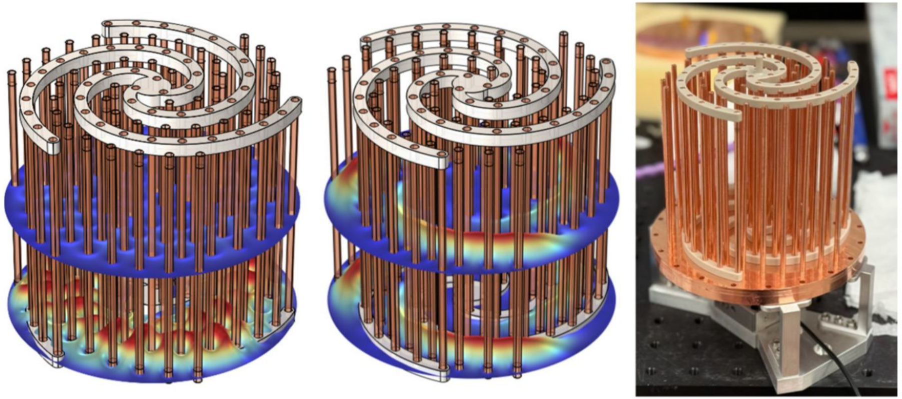
Olle Engkvists Stiftelse

An example of a plasma haloscope: The spiral cavity



(a) 30° (b) 15° (c) 0°

Low frequency High frequency

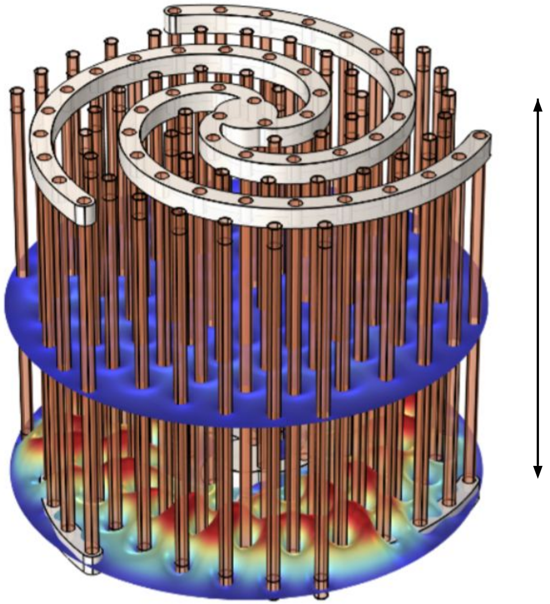


- Wires on spiral arms
- Turn one set of spirals relative to another
- Example shown: tunes from 9.7 to 12.7 GHz
- Currently being used for a dark photon run at Yale!
- Published in PR Applied: *J. Lindahl et. al. Phys. Rev. Applied* ***25****, 024073*

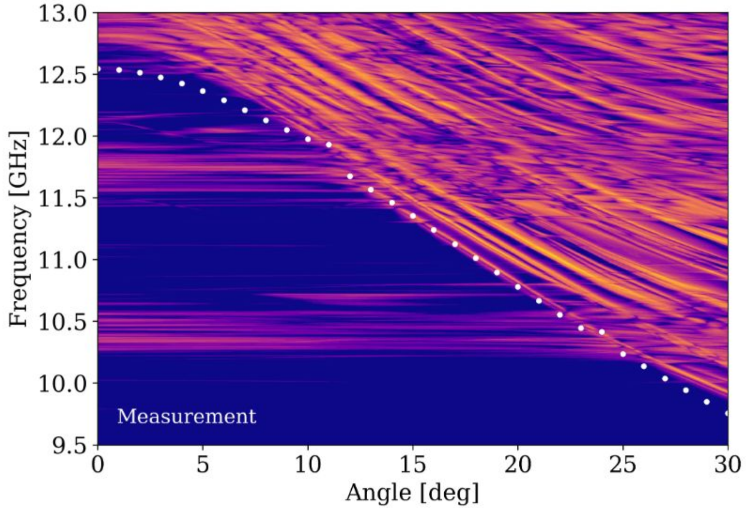
An issue with the existing spiral cavity

Fixing structure:

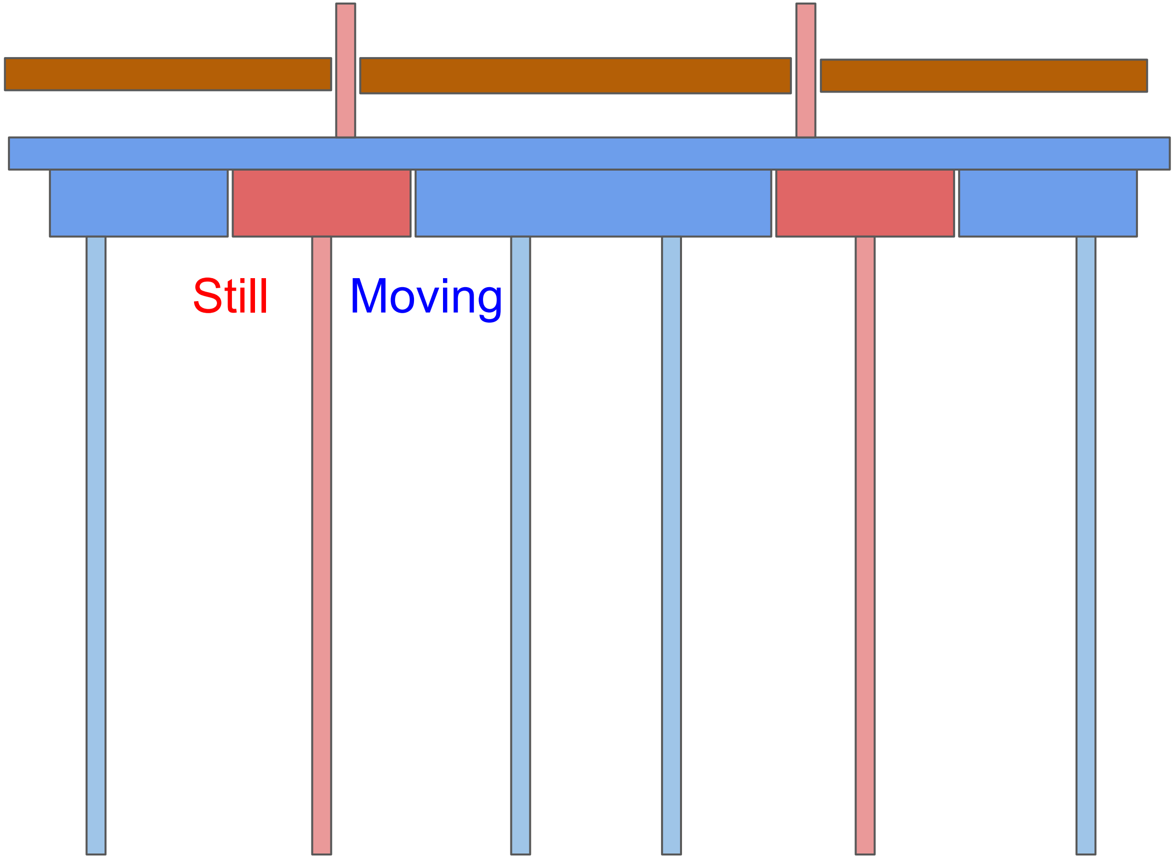
- ❖ Complicated geometry
- ❖ Causes mode mixing



Longitudinal symmetry is broken with the spiral arm fixtures

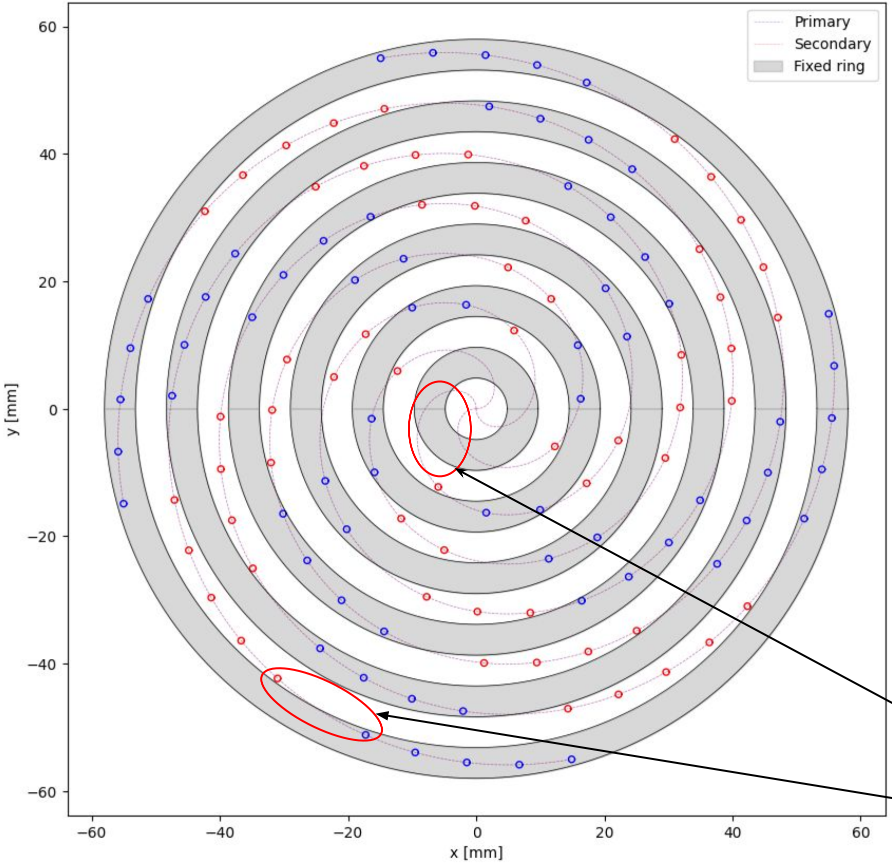


A flush inner surface



- Put still and moving rods on different concentric rings
- Mount all moving rods into one plate and move them together
- Inner surface is flush
- **One single rotation axis!**

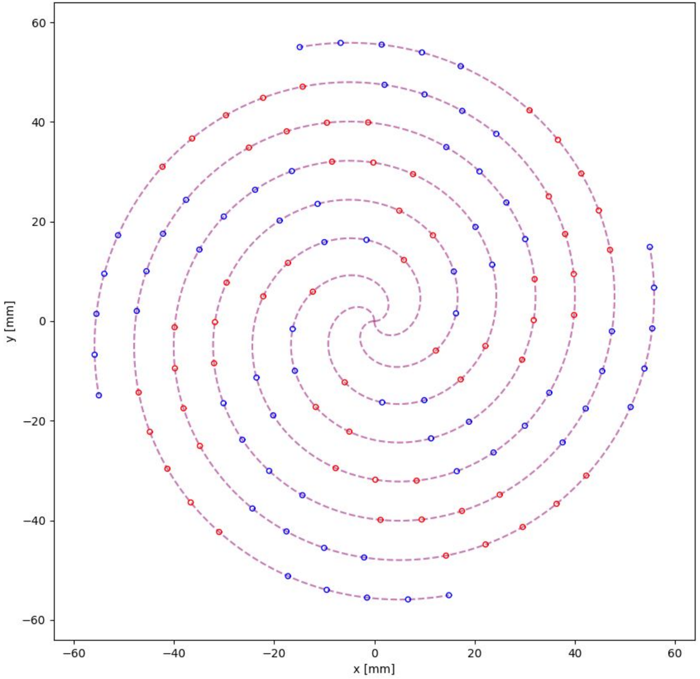
Rinnegan cavity: **Ring Nested Group Rotation**



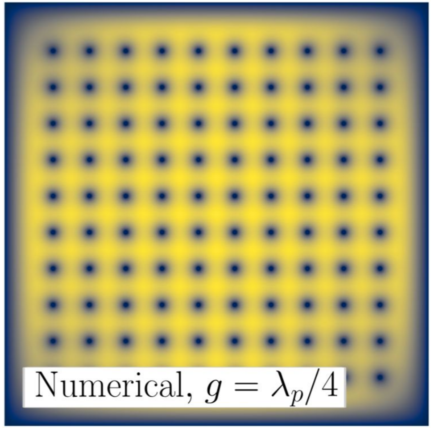
- Spirals are broken up along concentric rings
- ***Sections*** of a spiral move relative to each other

Intersection points feature gaps (or off-spiral wires)

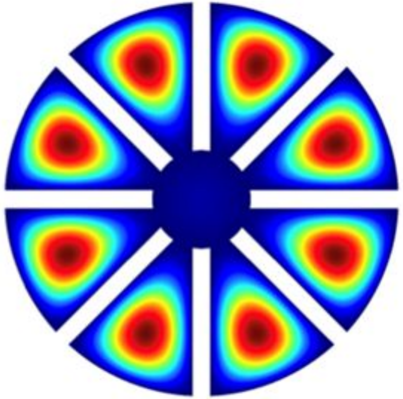
A Broken Spiral on Concentric Rings



- Blue wires are on fixed rings
- Red wires are on moving rings
- **One single motor rotation!**
- Transitions from “uniform” to “pizza cavity”



Phys. Rev. Applied ***23****,* *054053 (2025)*



Phys. Rev. Lett. ***125****,* *221302 (2020)*

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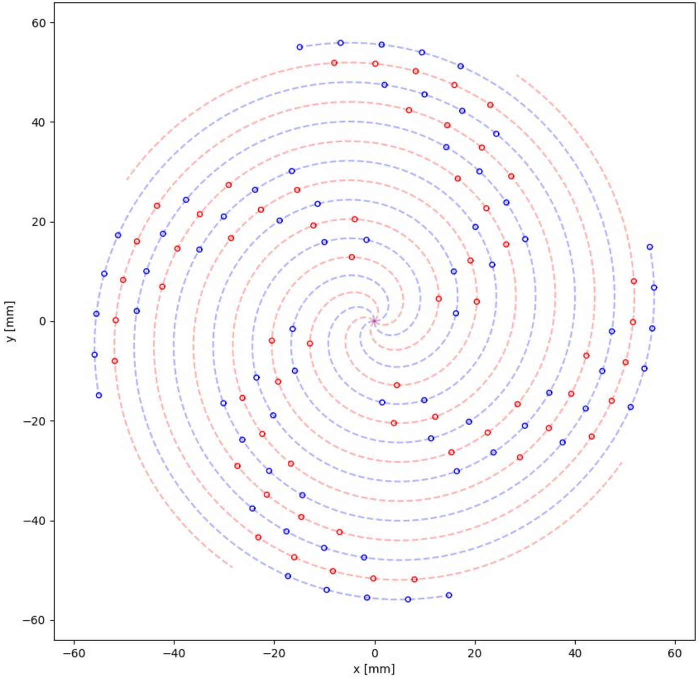

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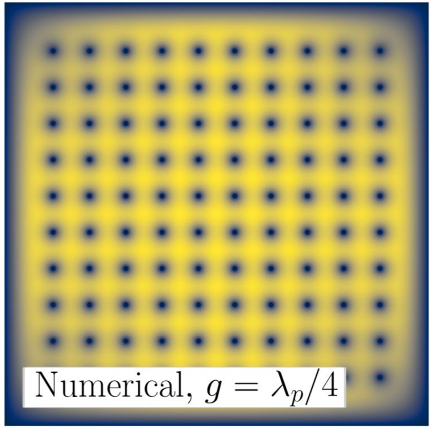

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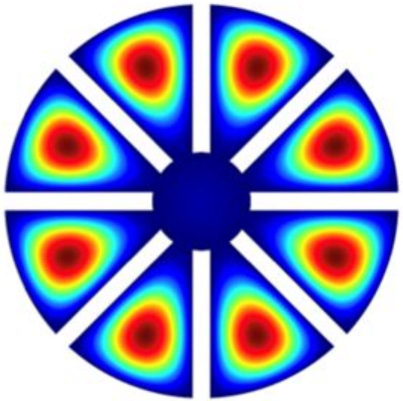

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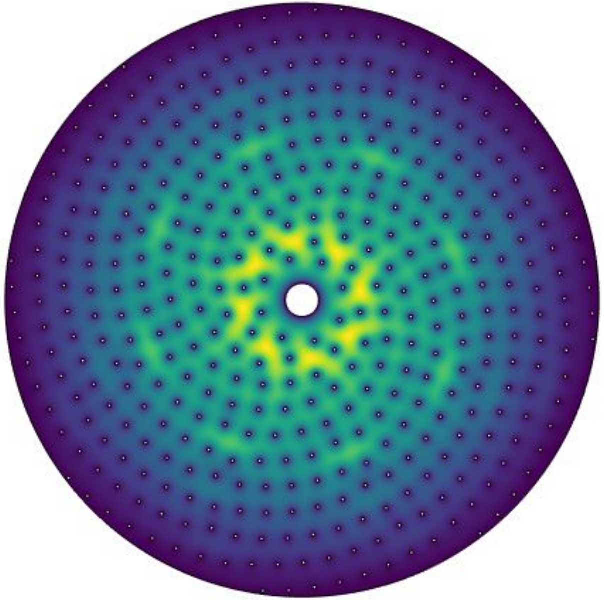
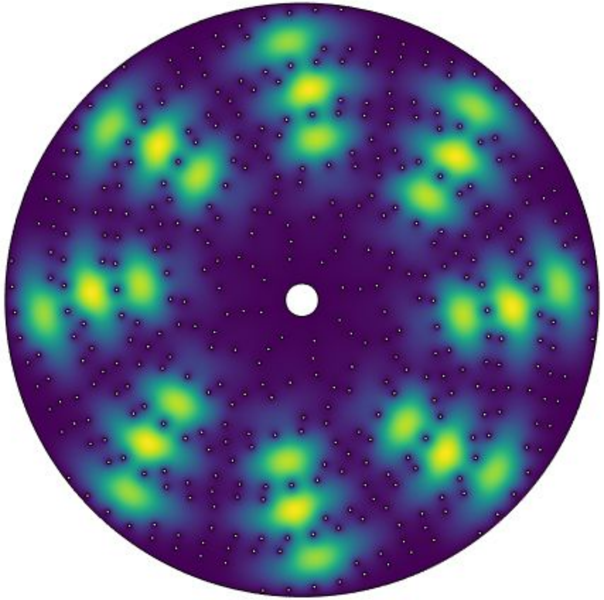
Field simulations

- Uniform
- High f_0



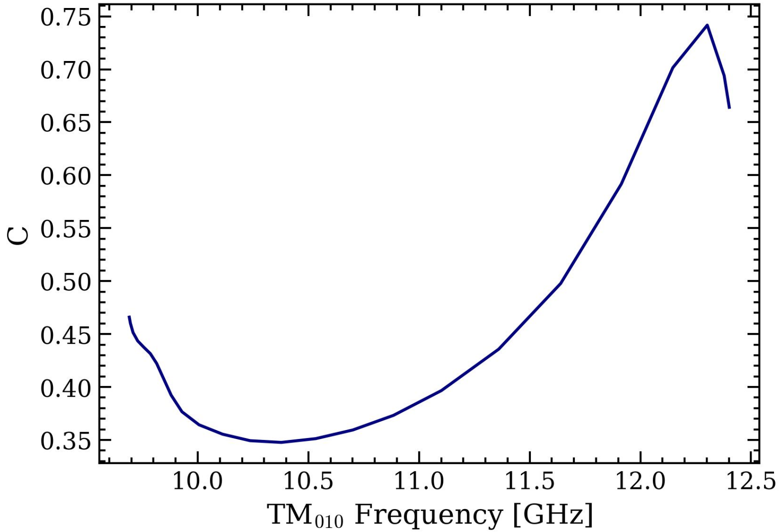
$\theta = 0$

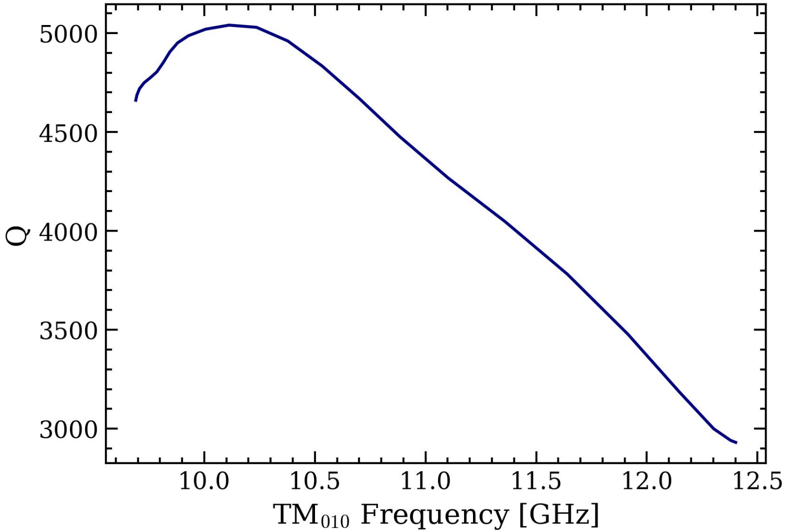
- Pizza
- Low f_0



$\theta = \pi/8$

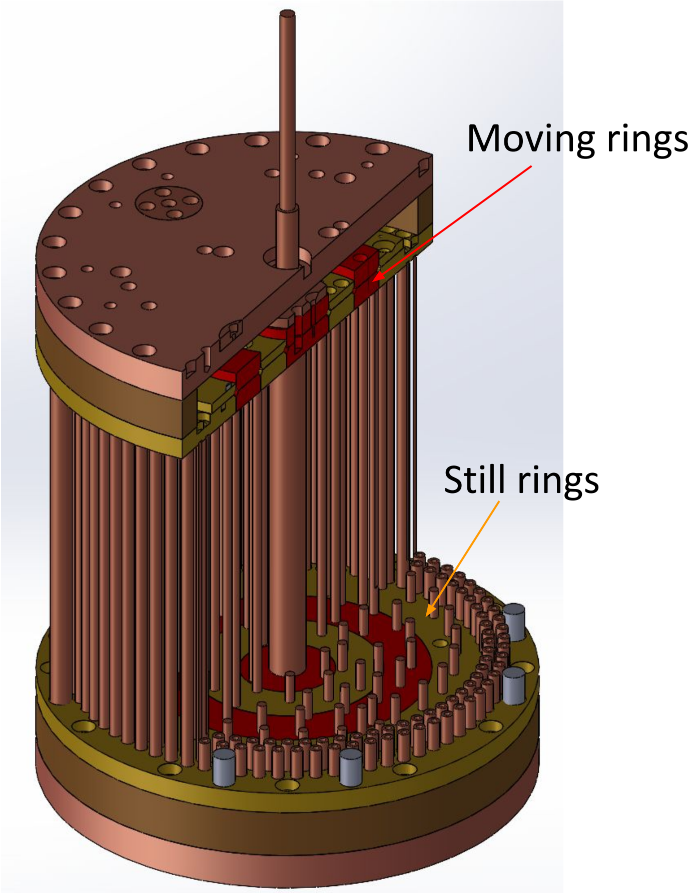
Frequency Range and Form Factor

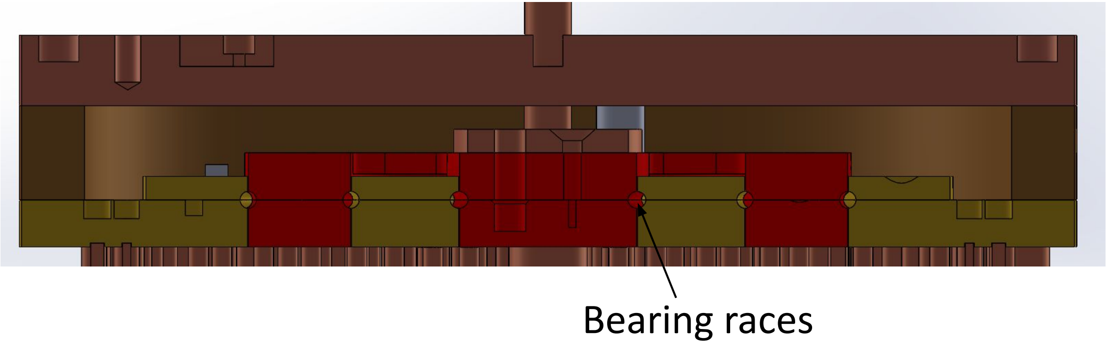




- Tuning range from 9.7 GHz to 12.4 GHz
- Maintains a reasonable form factor for 1mm wires
- Quality factor decreases for thin wires

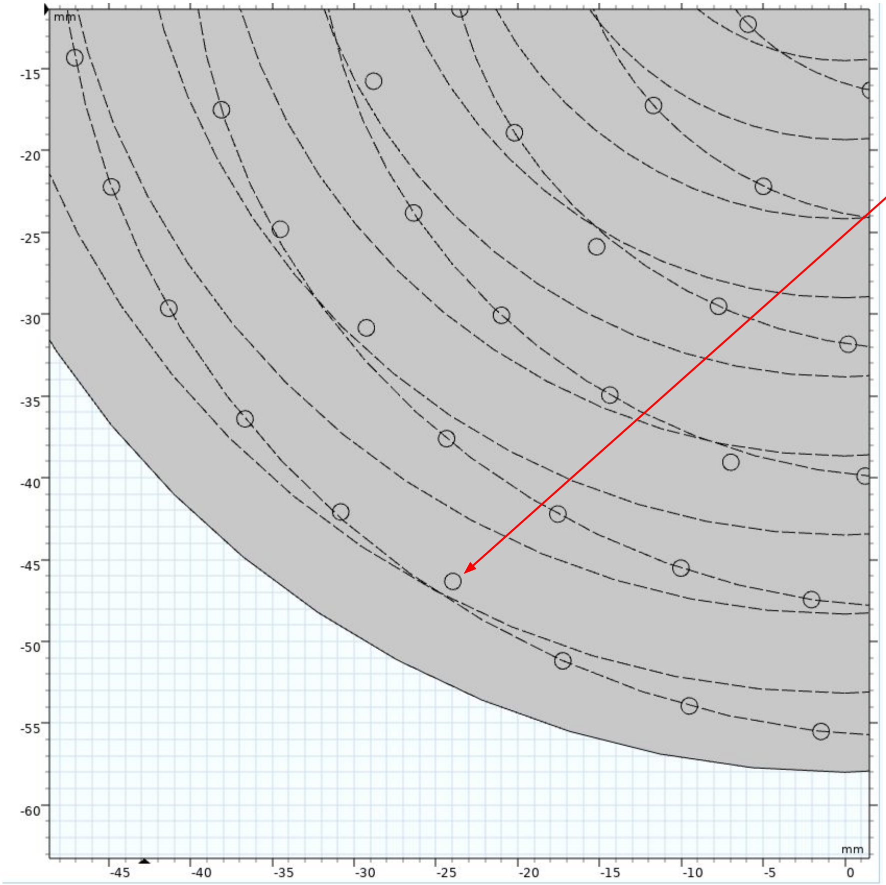
Ongoing prototyping for the Rinnegan cavity





- 4 rings
- 3 spirals
- 25 wires per ring
- 2.5 mm diameter wires
- 100 µm gaps between rings

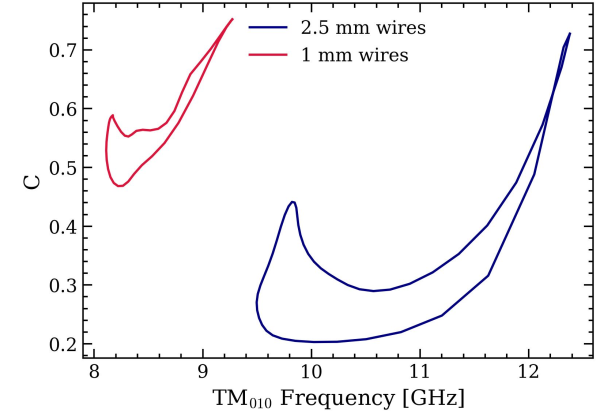
Potential drawback #1: Wires that intersect the rings



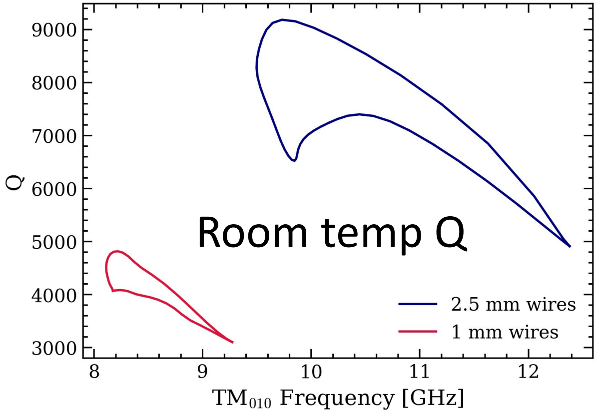
Removed wires create a gap for the field to localize

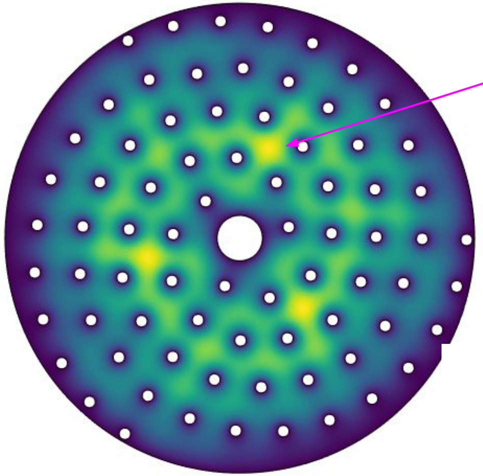
- Degrades form factor
- Must be reintroduced with a slight offset

Potential drawback #1: Wires that intersect the rings



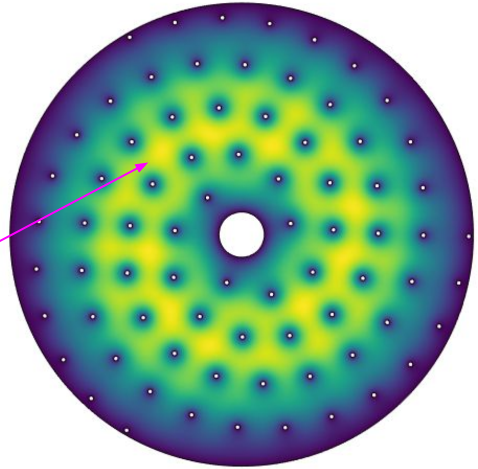
Not an apples to apples comparison!





Thicker wires has more localization

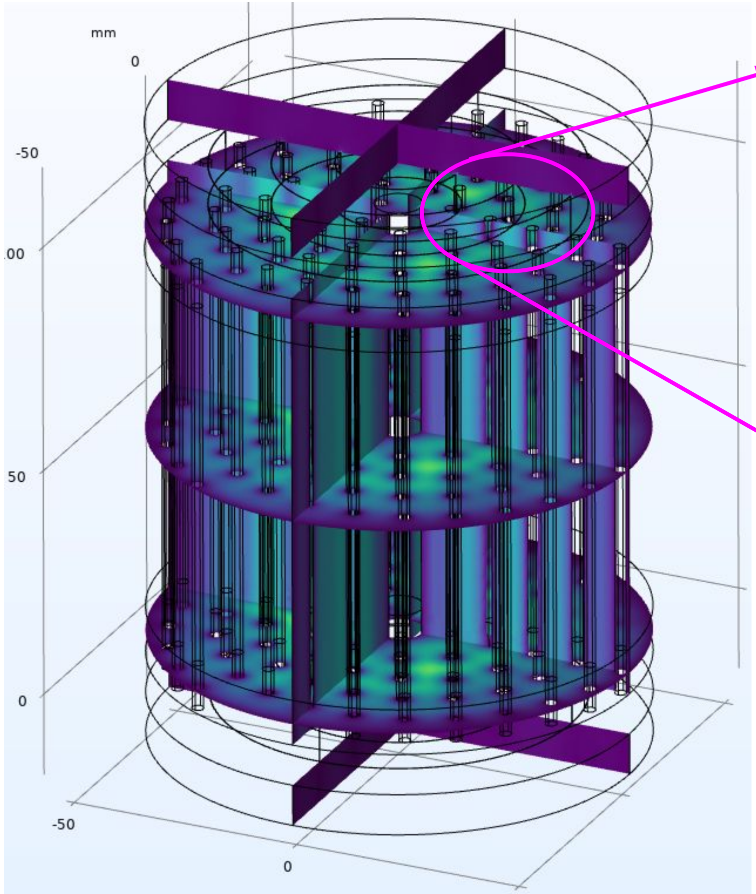
Offset can be as big as the wire radius

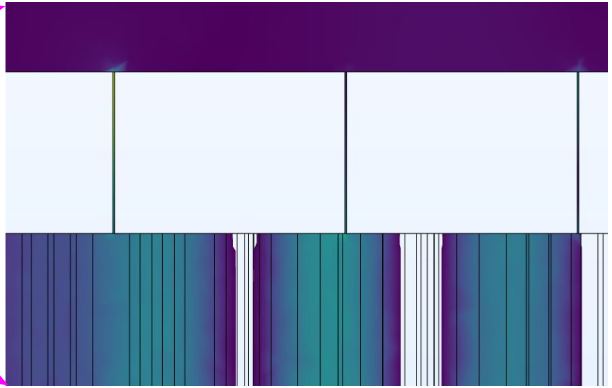


Thinner wires have less localization

But lower Q

Potential drawback #2: Losses due to seams



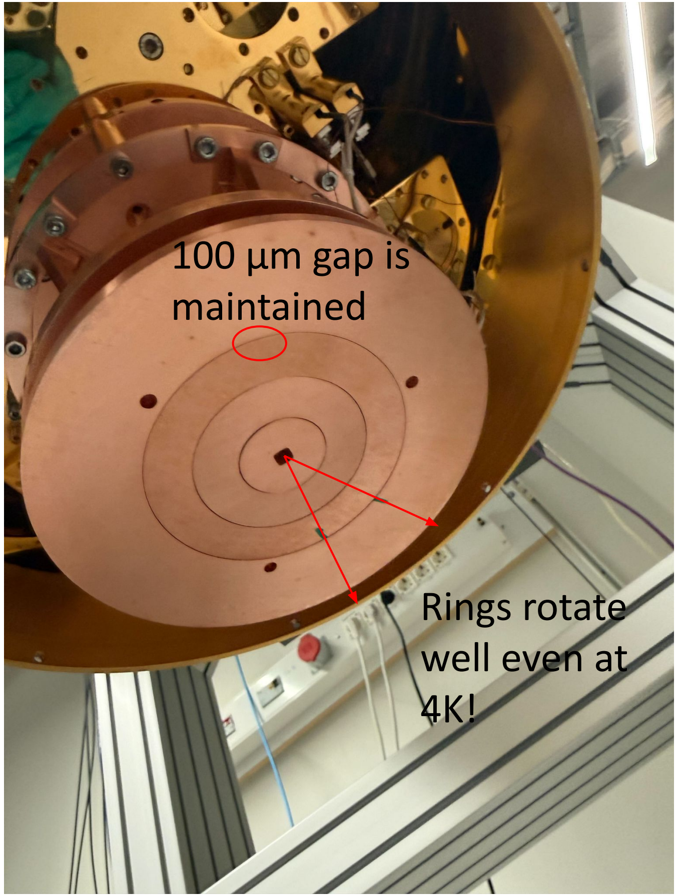


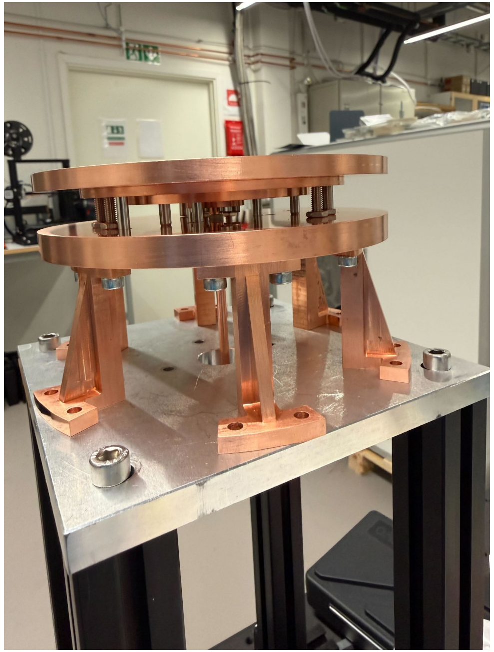
Some field is localized in the seams

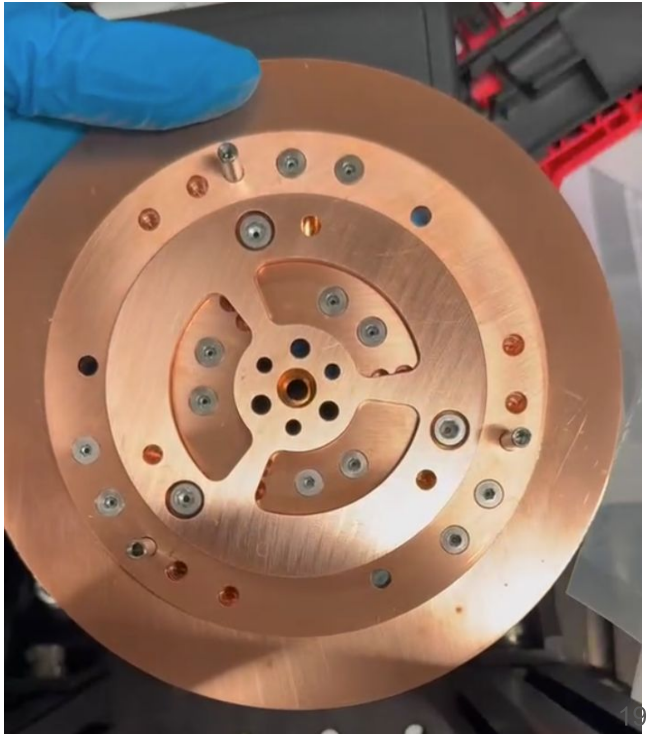
Q and C drop, but slightly at 100 µm gap

- Without seams (highest frequency TM_{010}):
  - Q = 4780, C = 0.73
- With seams:
  - Q = 4577, C = 0.61
- **Effect of ball bearings to be seen**

Cryogenic rotation tests







Thanks for listening!

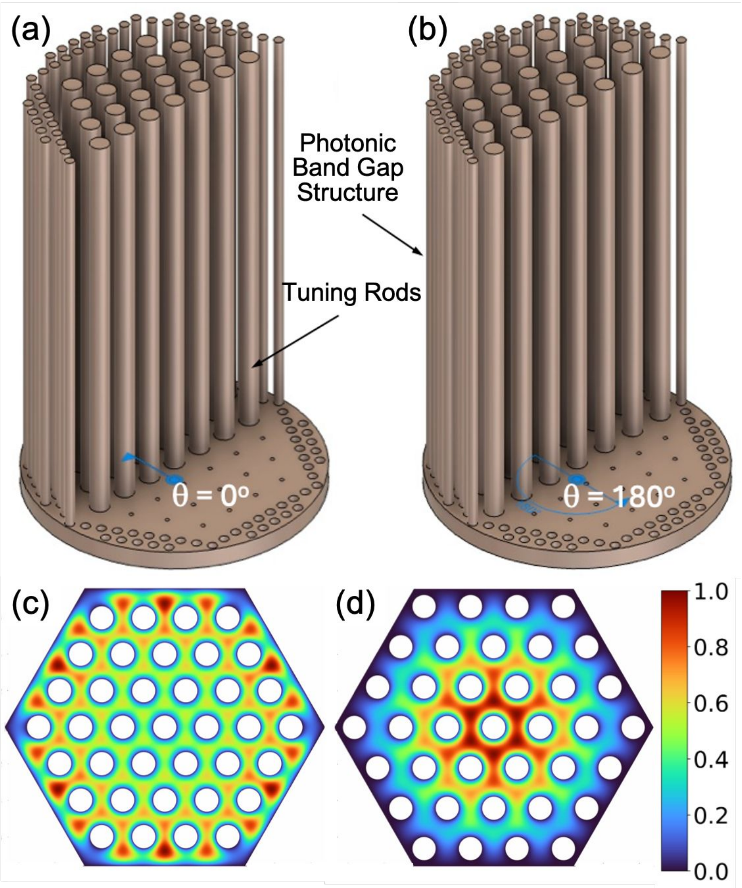
- Several GHz tunability to look for high mass axions
- Single rotating axis
- To be seen:
  - The effect of ball bearings and seams on Q
  - The optimal way of packing wires

Backup

ALPHA Timeline

- Currently commissioning the dark photon run with a prototype spiral cavity
- Resonator design is being finalized and production will begin soon
- Magnet delivery and full commissioning in 2027
- Physics data taking to begin in 2028

Berkeley cavity



- ❖ Preserves symmetry
- ❖ Thicker rods for high Q
- ❖ Off axis axle drives several rod axes