CAPP's Main Axion eXperiment (CAPP-MAX) with *High-Temperature Superconducting* Cavity

25th April 2025

OHJOON KWON ON BEHALF OF

CAPP-PACE TEAM & ALL CAPP MEMBERS
WHO PARTICIPATED IN THE CAPP-MAX

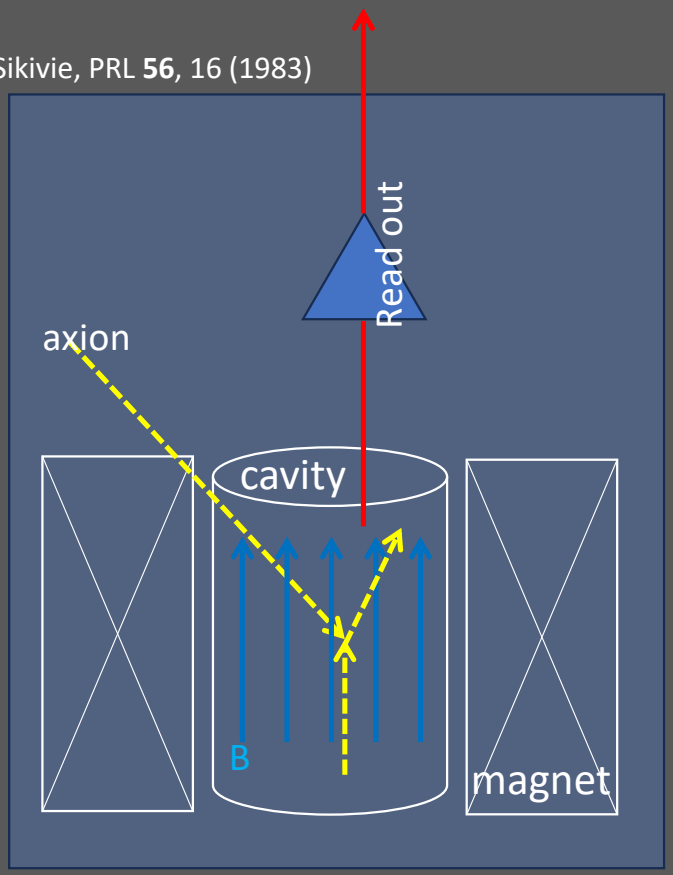
IBS-Dark Matter Axion Group (DMAG)
Daejeon, South Korea

Contents

- Axion haloscope
- CAPP's Main Axion eXperiment (12T/32cm)
- HTS-ReBCO microwave cavity in CAPP
- CAPP's main axion experiment (CAPP-MAX) w/ HTS-ReBCO cavity
- Summary & Future plan

Axion haloscope

P. Sikivie, PRL **56**, 16 (1983)



D. kim, et al, JCAP03(2020)066

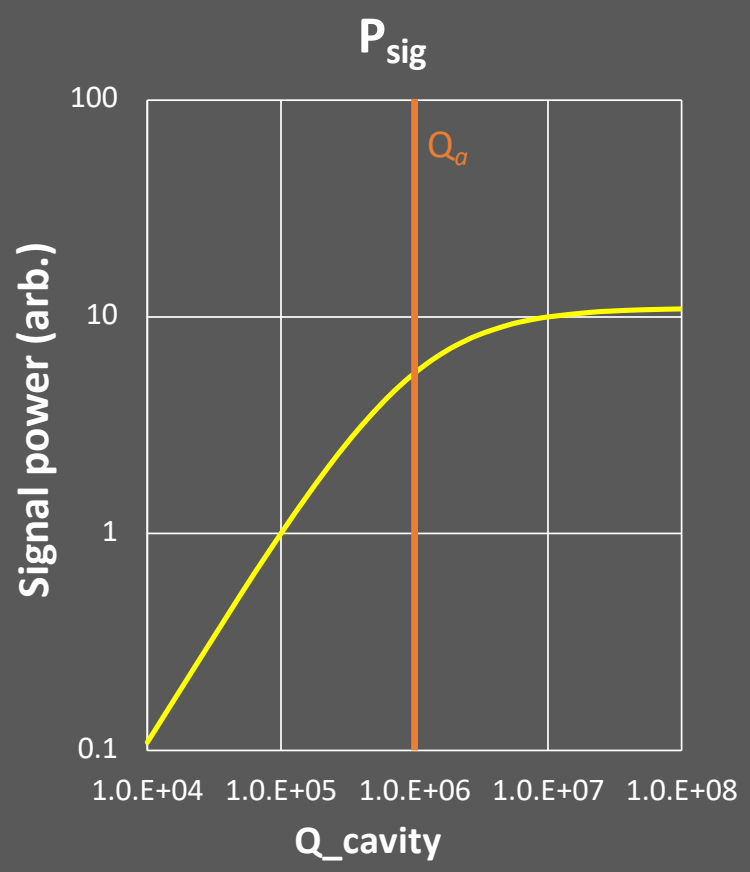
$$P_{sig} = g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} \frac{\beta}{1+\beta} B^2 V C Q_{all}$$

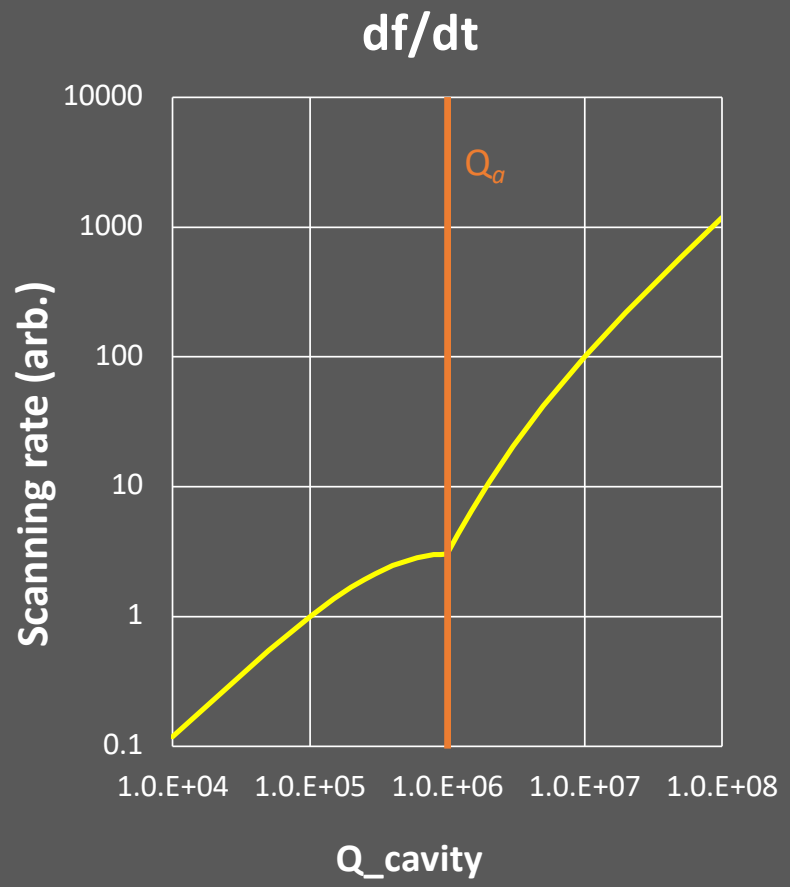
$$\frac{1}{Q_{all}} = \frac{1}{Q_0} + \frac{1}{Q_{ext}} + \frac{1}{Q_a} = \frac{Q_L + Q_a}{Q_L Q_a}$$

$$\frac{df}{dt} \propto \frac{B^4 C^2 V^2}{T_{sys}^2} Q_{all}$$

High-Q boosts axion scanning speed

D. Kim et al., Physics A *(2020), 03* R. Cervantes et al., Phys. Rev. D 110, 043022

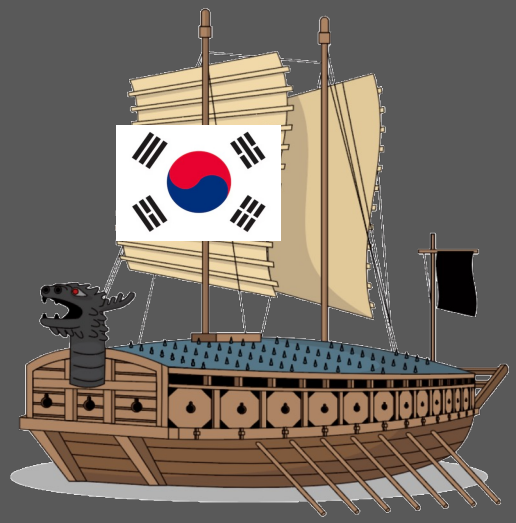




CAPP's main axion experiment (CAPP-MAX)

**Phys. Rev. X 14, 031023 (2024)

- CAPP's flagship experiment to search for axion above 1GHz
- Dine-Fischler-Srednicki-Zhitnitsky (DFSZ) sensitivity



CAPP's main axion experiment (CAPP-MAX)

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- CAPP's flagship experiment to search for axion above 1GHz
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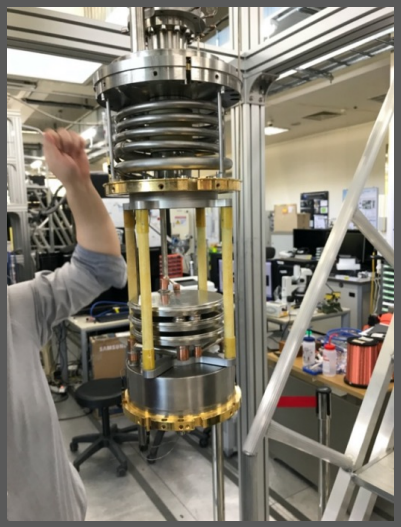
12 Tesla SC magnet
320mm bore diameter
By Oxford. Inc

+



Dilution refrigerator
T_{base} ~ 5.6 mK
By Leiden

+

JPA (quantum amplifier)
$>$ 1 GHz
By collaboration w/ Tokyo Univ.
RIKEN

+

?

Large cavity

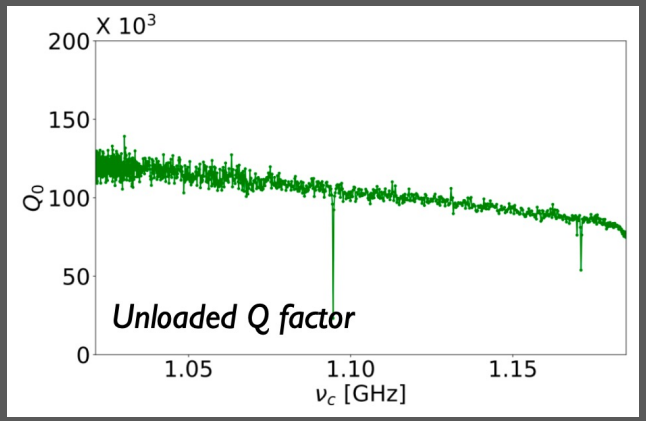
- maximum volume
- high Q
- easy cooling
- frequency tunable

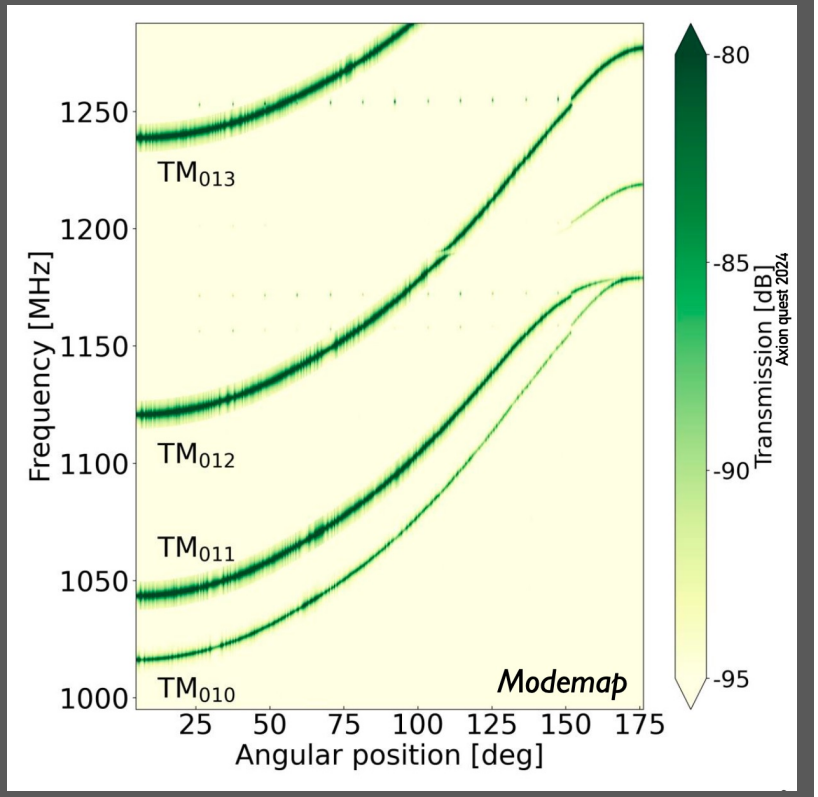
Ultra-light cavity (ULC) for CAPP-MAX

*Phys. Rev. Lett. 130, 071002 (2023).

**Phys. Rev. X 14, 031023 (2024)

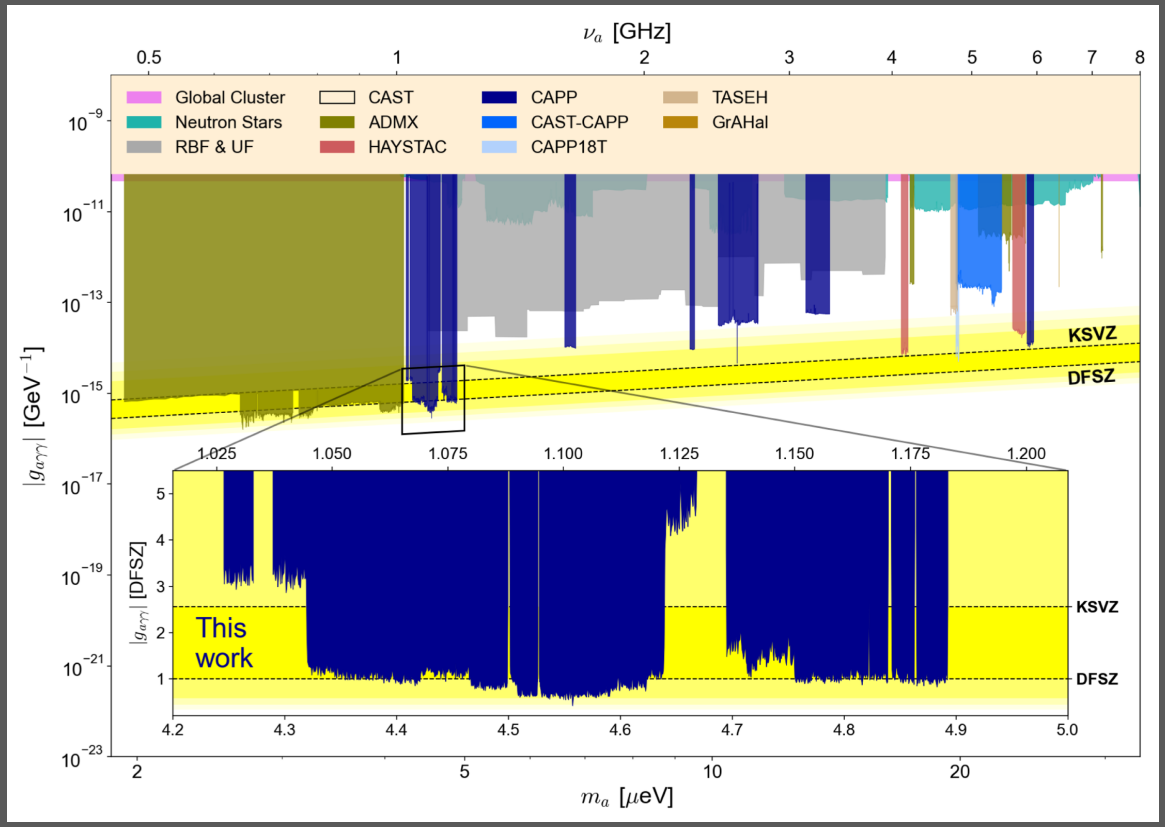
- 37L, total ~6kg
  - Easy tuning
  - Fast cooling
- Q_0 > 170k w/o tuning rod
  >100k w/ tuning rod





Recent progress of CAPP-MAX

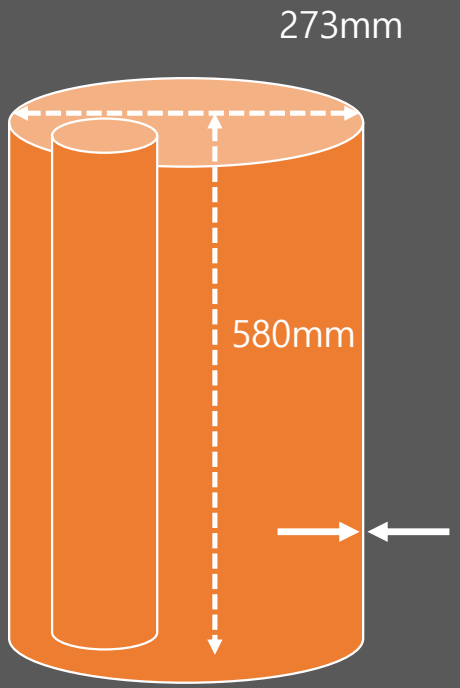
**Phys. Rev. X 14, 031023 (2024)

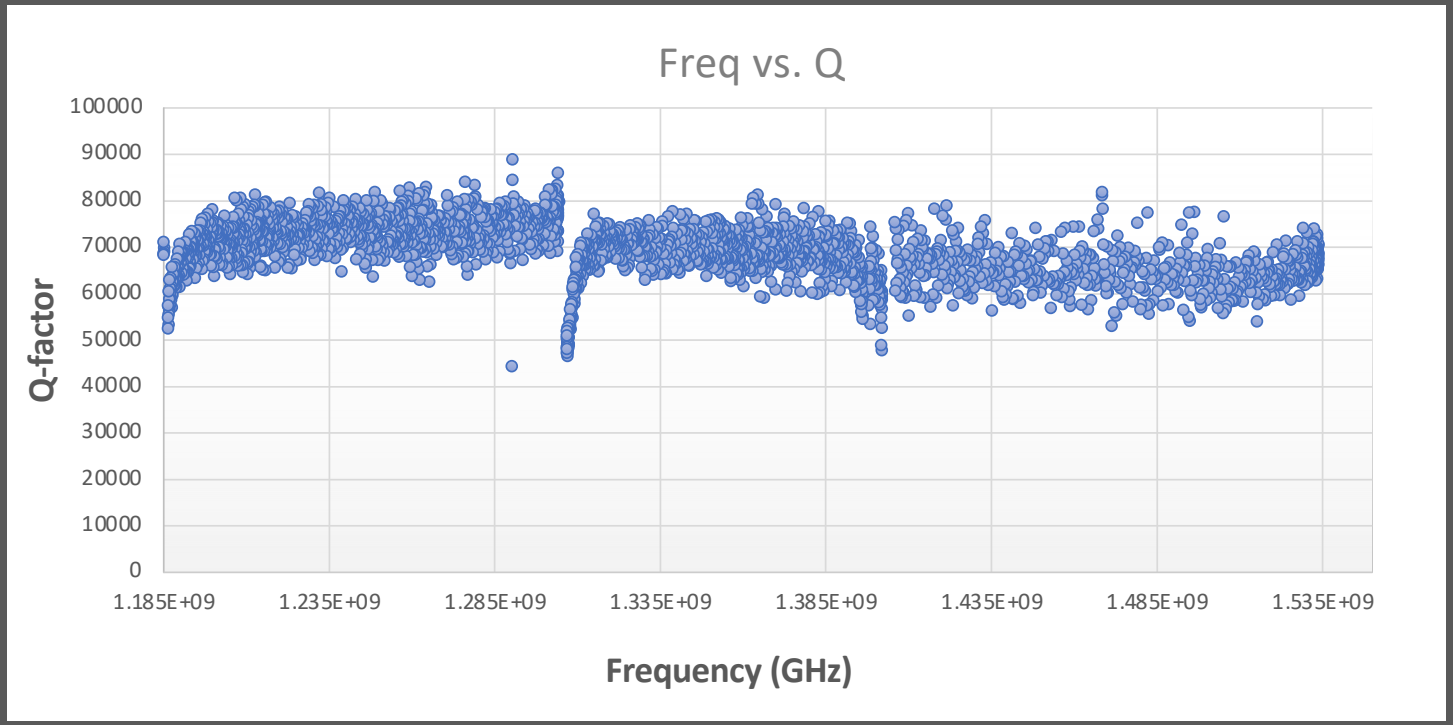


- 1.024-1.18GHz scan completed
- T_{phy} ~ 30mK
- T_{sys} ~ 230mK
- 3 parallel JPAs readout
- 3MHz/day in DFSZ sensitivity

Next cavity for CAPP-MAX?

1.18– 1.53 GHz ***Typical copper cavity*** ➔ Less volume, Less Q-factor





Next cavity for CAPP-MAX?

CAPP's HTS-ReBCO cavity

- Vertical movment of sapphire rod
- Axion experiment performed

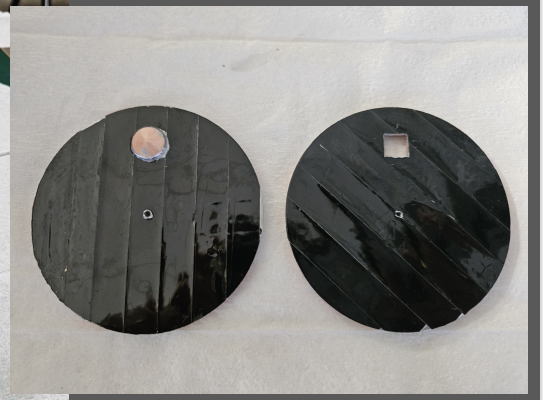
See Dr. D.Ahn's talk

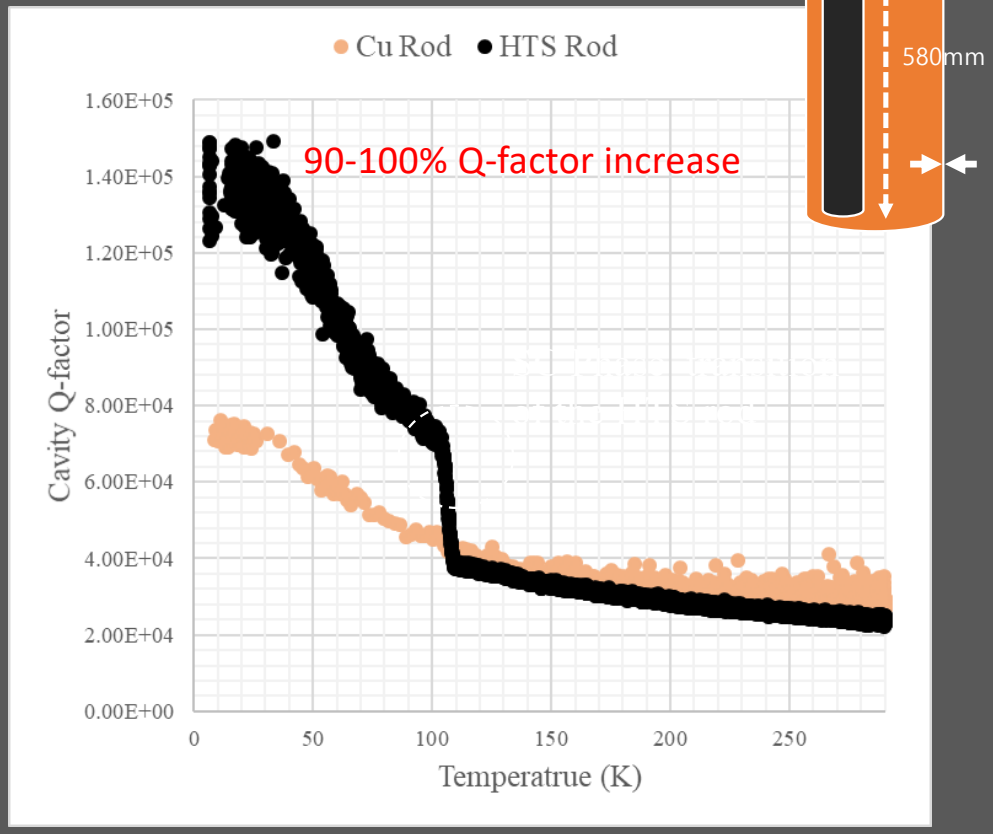
- CAPP's first >1M Q-factor HTS cavity
- AQN experiment performed

- CAPP's best Q-factor so far

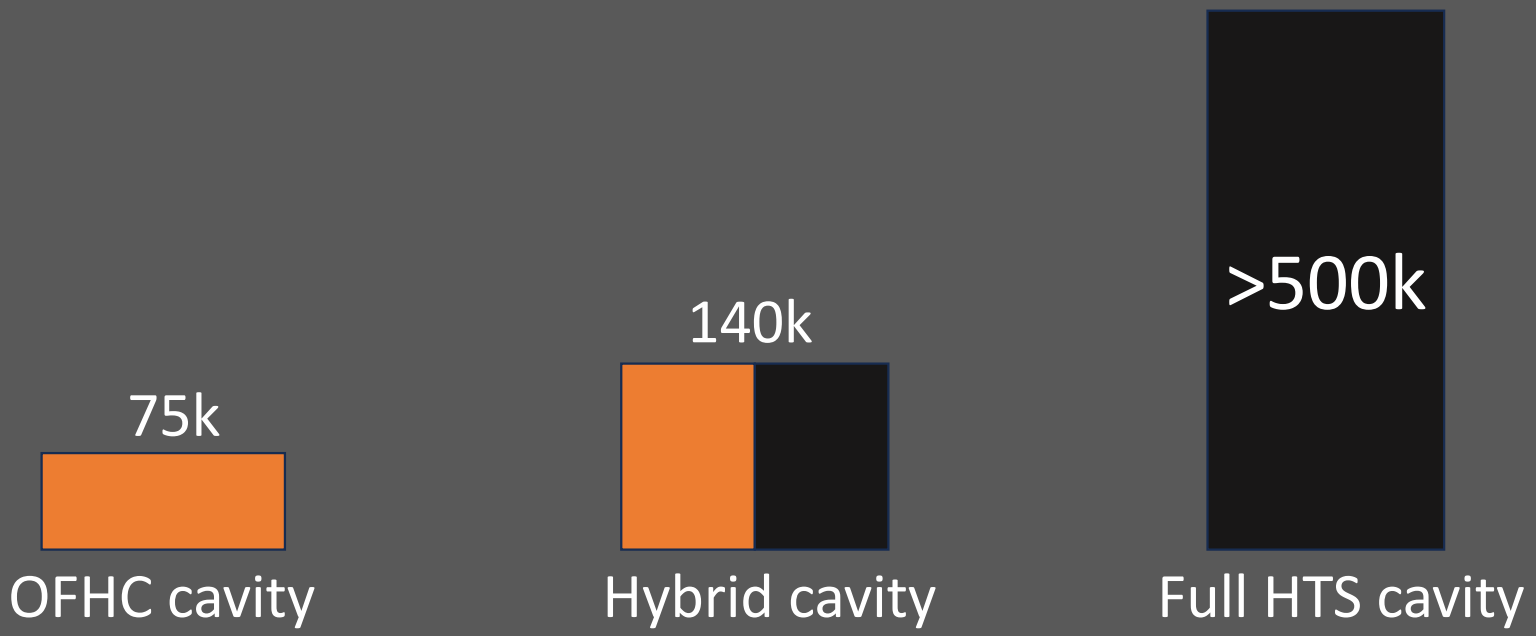
Next cavity for CAPP-MAX?

1.2– 1.5GHz ***Hybrid cavity: HTS tuning rod***





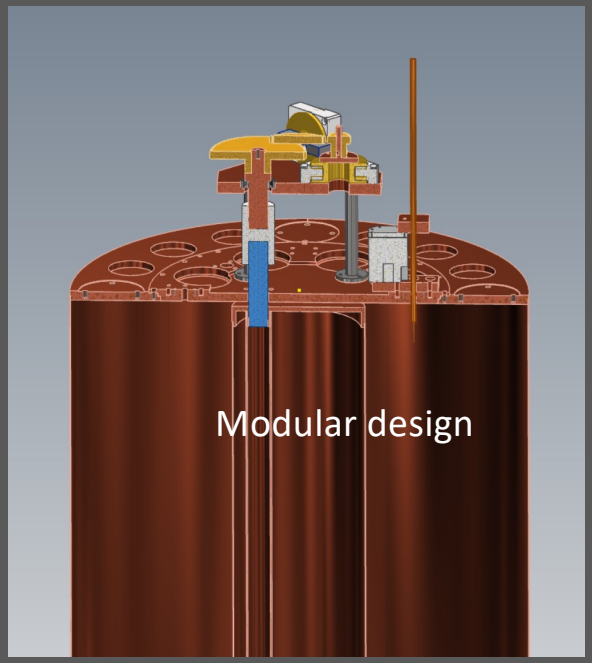
Next cavity for CAPP-MAX?

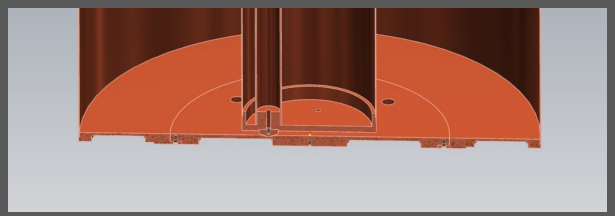


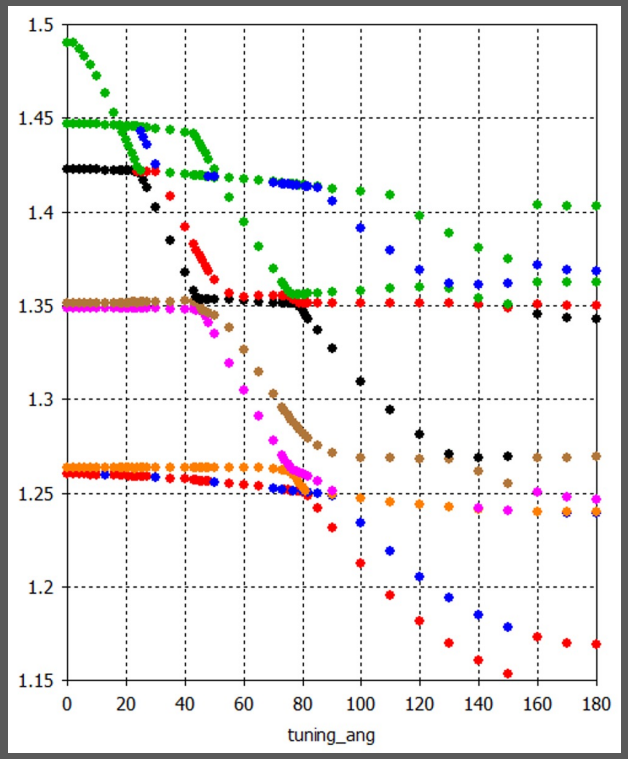
At least 6 times faster scanning

1.2-1.5 GHz cavity for CAPP-MAX

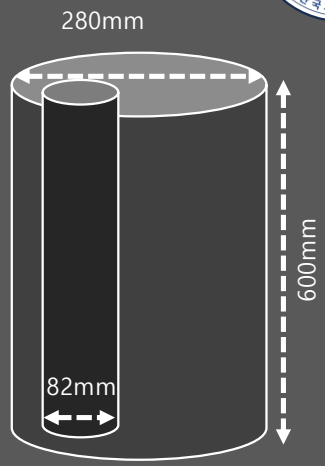
: Full HTS cavity

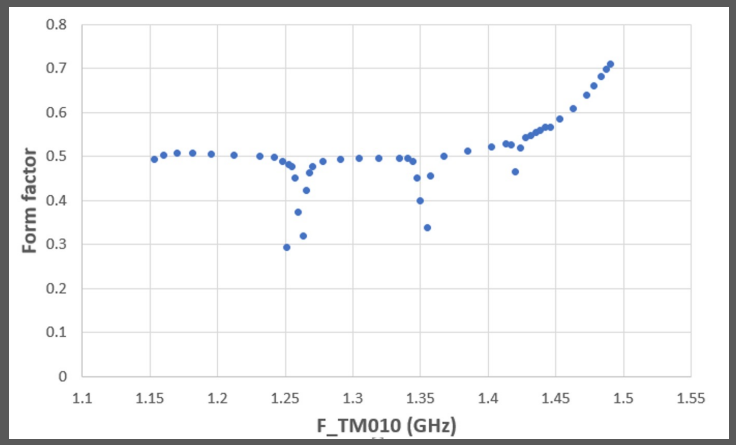






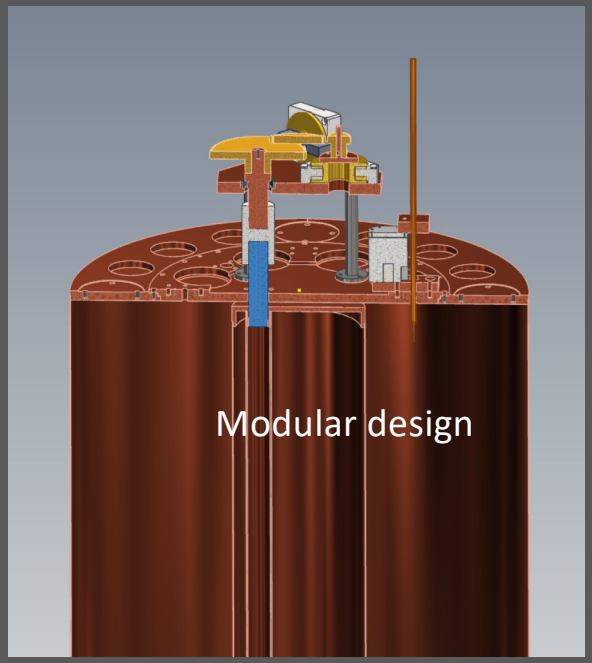
*CST MWS simulation

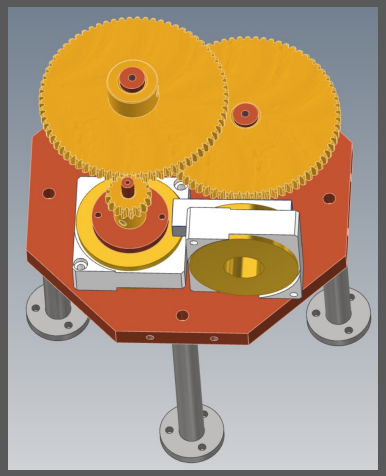


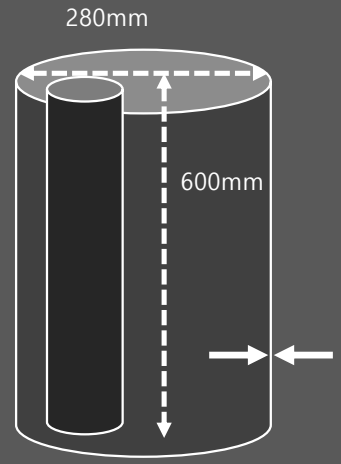


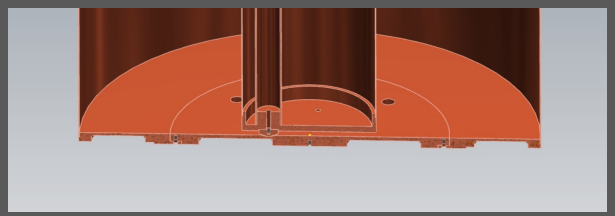
1.2-1.5GHz cavity for CAPP-MAX

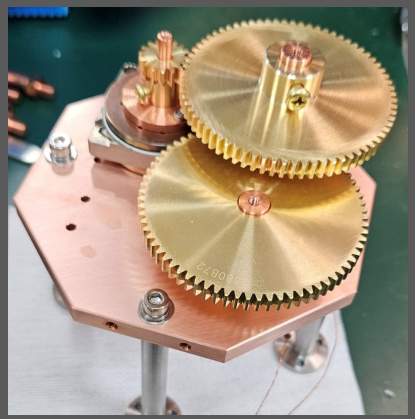
: Full HTS cavity







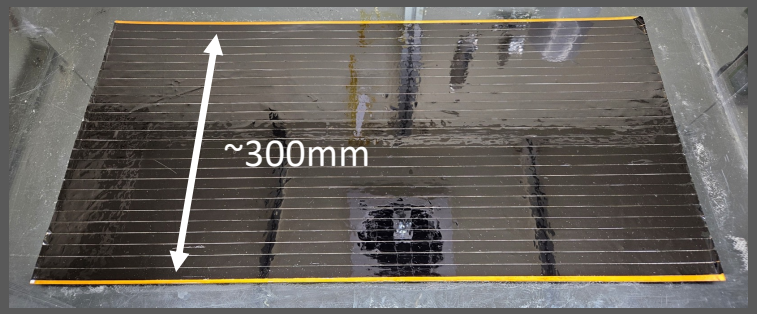


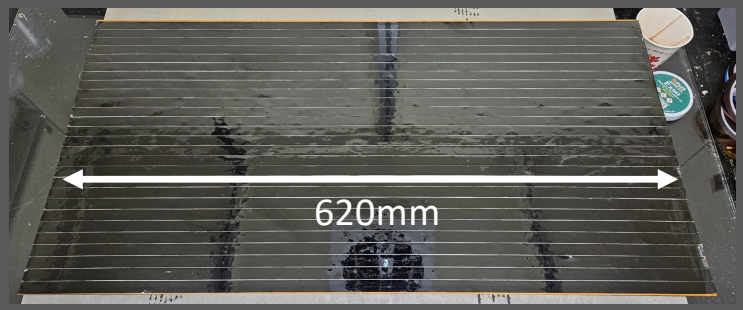


Gearbox (1:20) is ready
to move HTS tuning rod

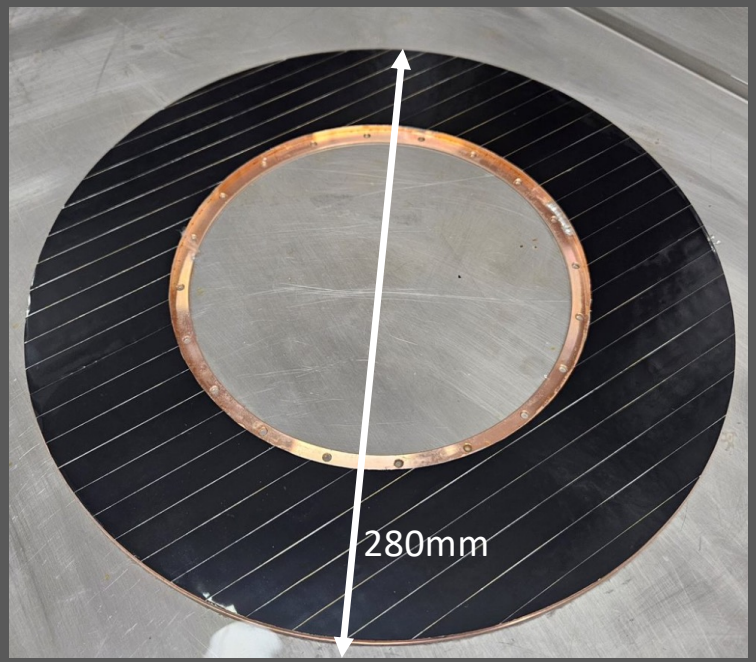
Covering HTS on copper parts

On side wall

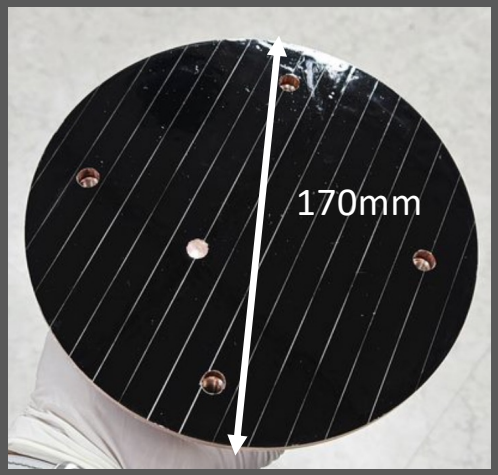




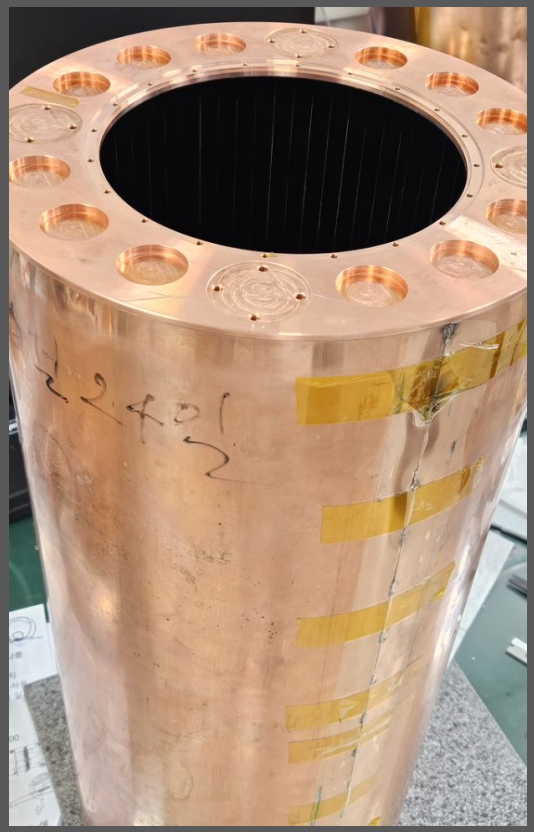
Cavity top-outer plate

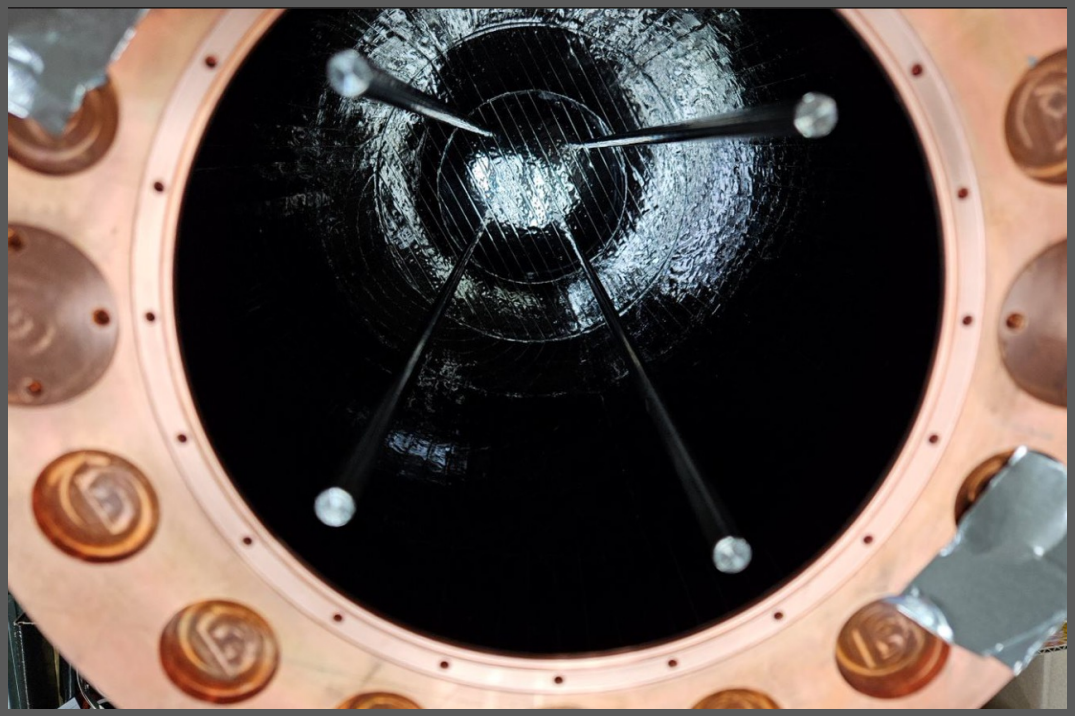


Cavity top-inner plate



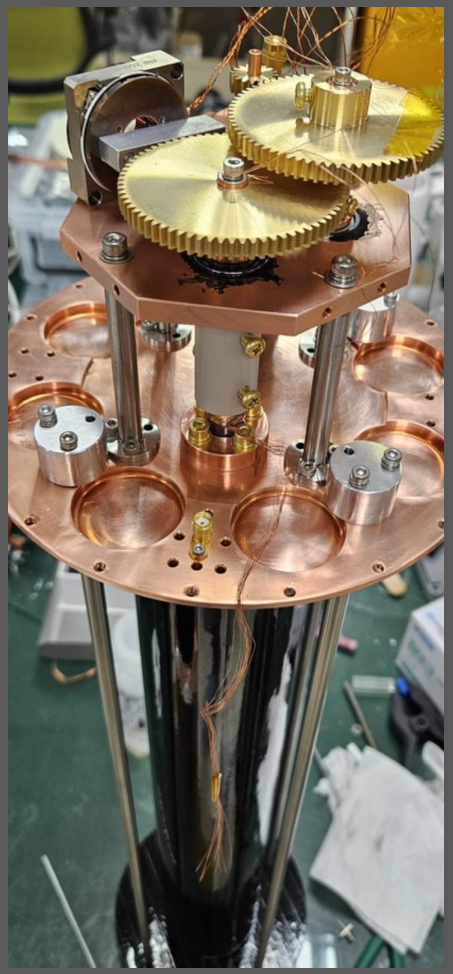
Connecting to endcaps → cavity frame!





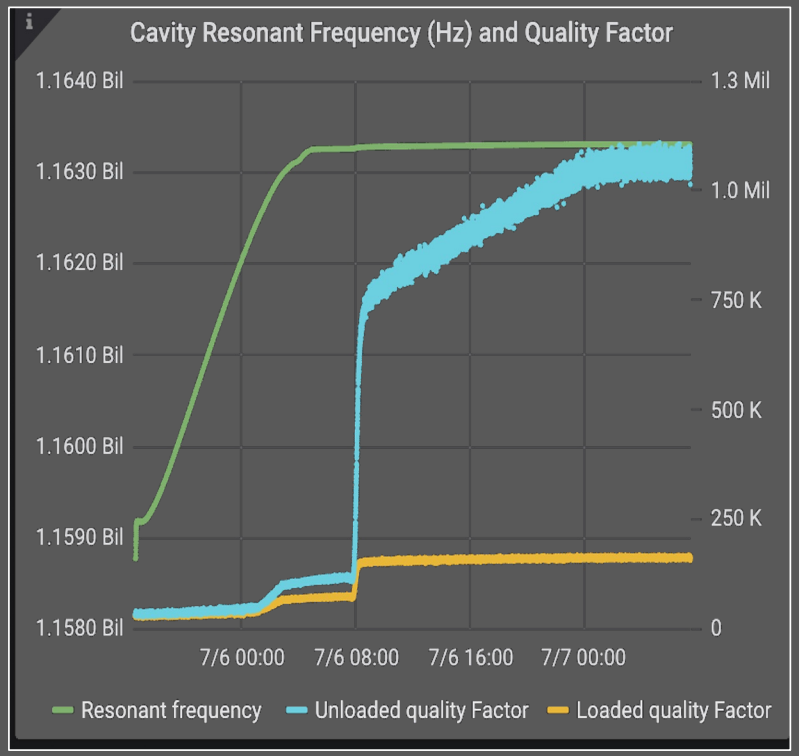
Tuning rod & gear box

Gearbox (~1:20) is designed to move HTS tuning rod

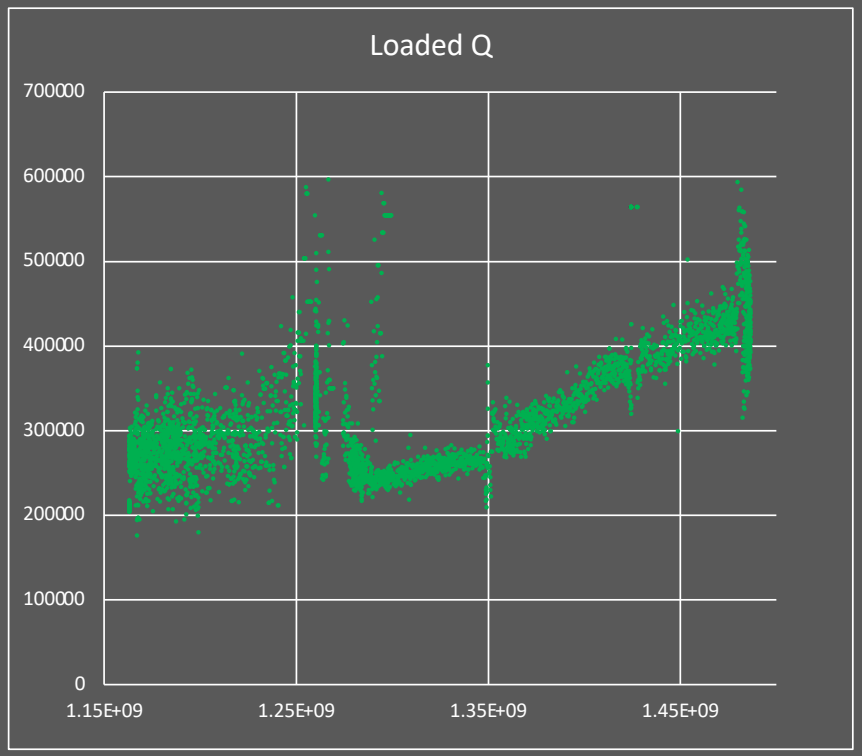


Full HTS cavity in CAPP-MAX system

During cooling down @1.163 GHz

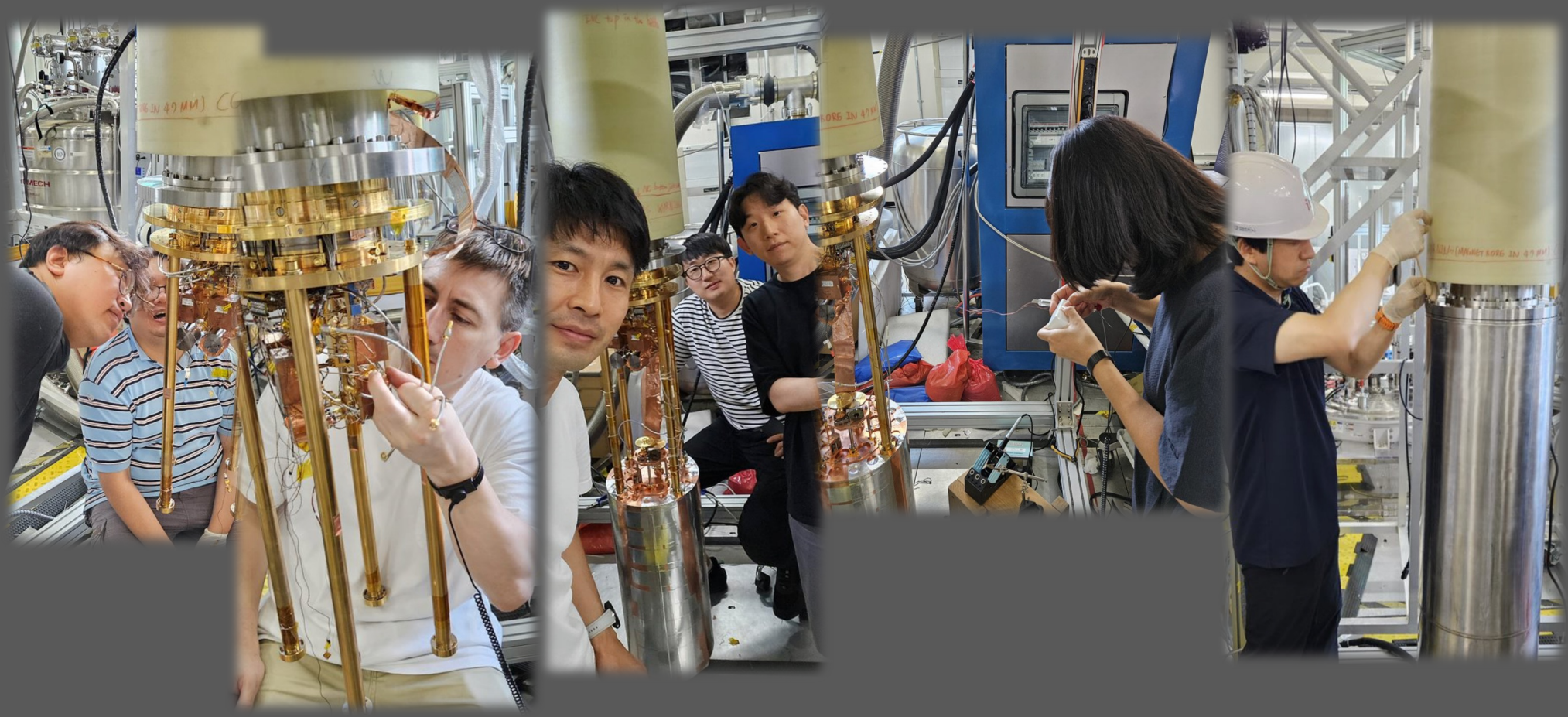


w/ frequency tuning



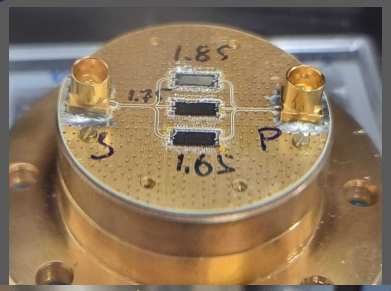
- **The unloaded Q-factor: 0.5 – 1.2 milion. $Q_{average}$ ~ 0.8milion**
- **Gearbox works well, *20V* piezo bias voltage can tune the cavity**

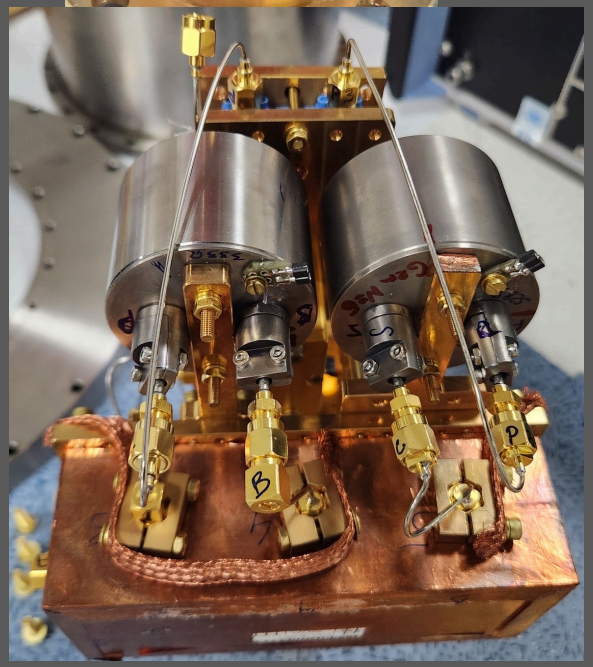
Combined efforts on CAPP-MAX

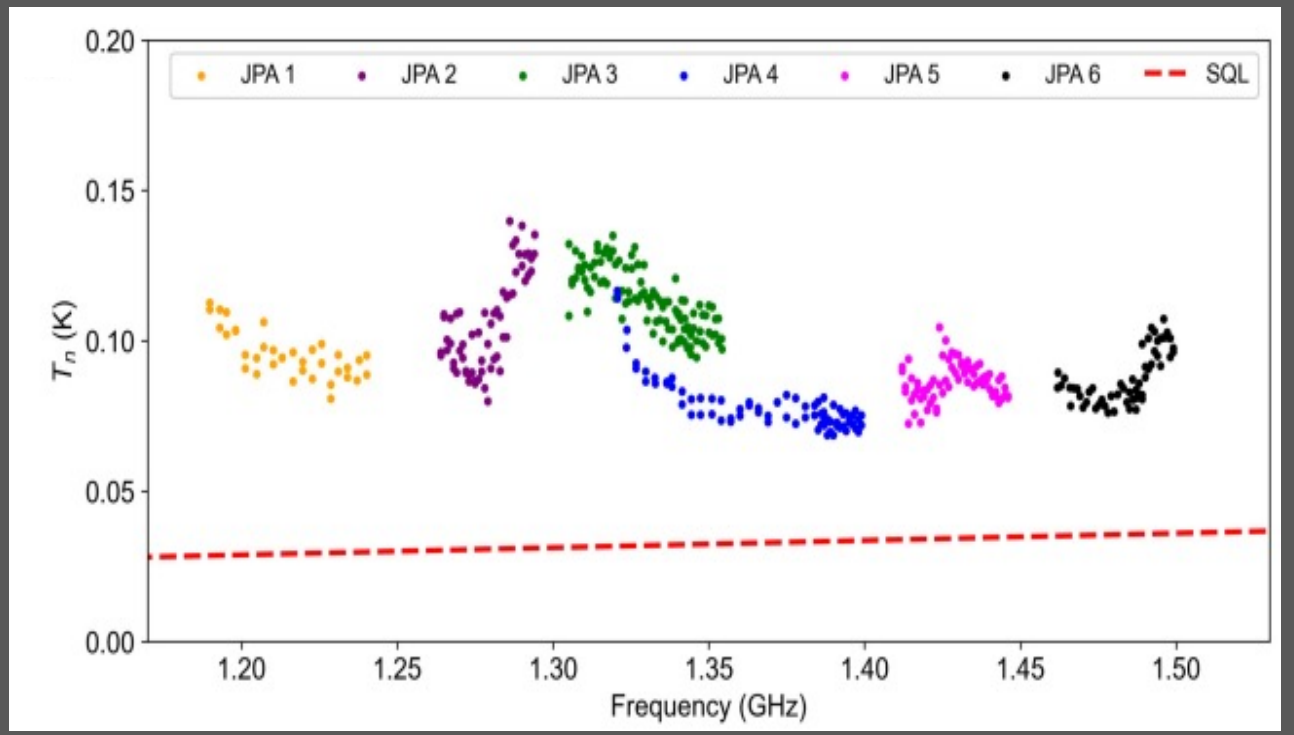


CAPP-MAX run: 6JPAs are installed

(Dr. Sergey Uchakin presented on Tuesday)







CAPP-MAX run: 0 field data

Before applying Magnetic field, ~13MHz of 0 field data obtained to optimize DAQ system.

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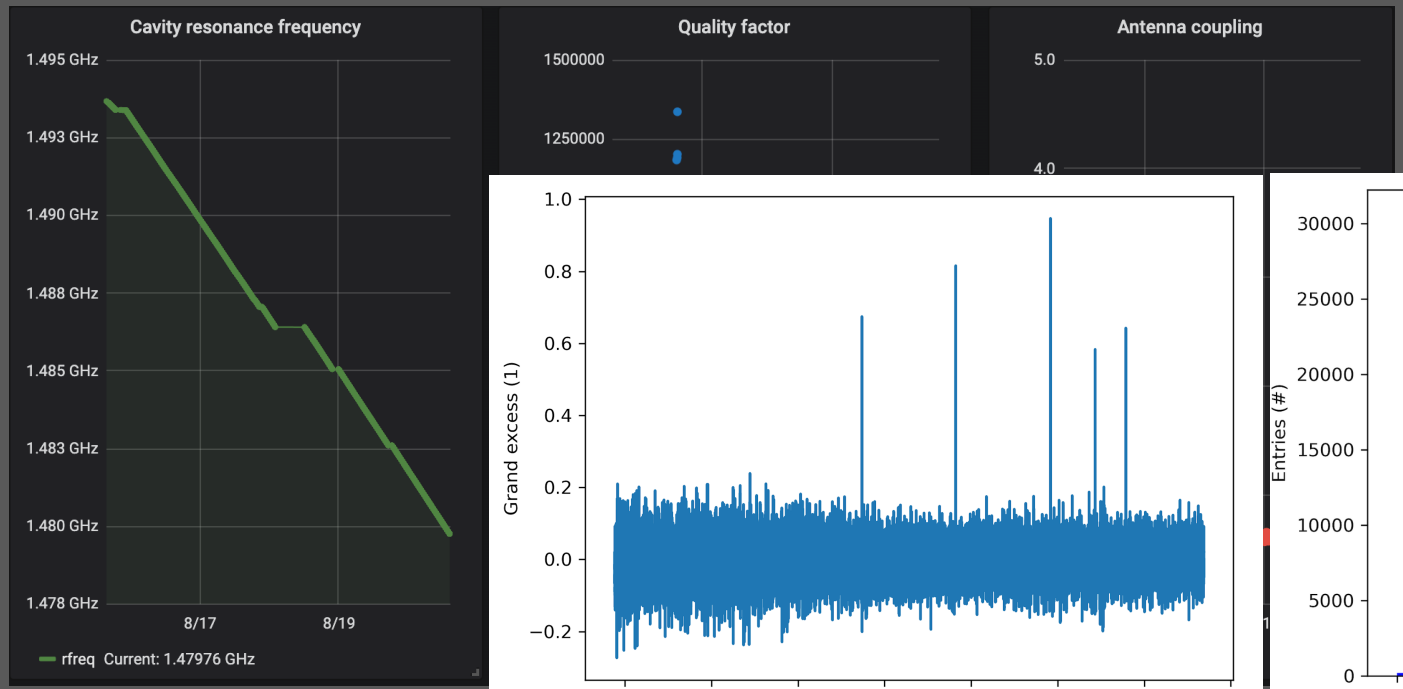

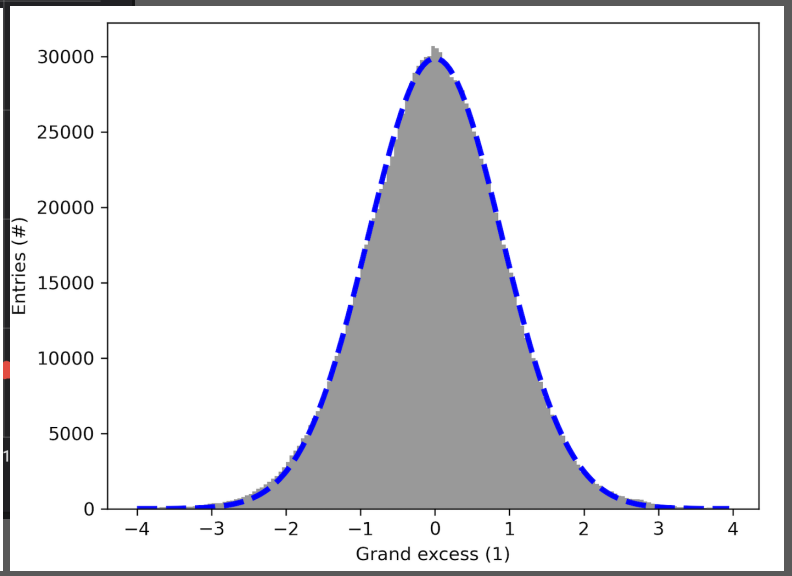

CAPP-MAX run: Q-factor w/ Bfield

w/ 11.2 tesla,
we achieved 1M around 1.3GHz

However,
we had to warm up the system
due to …

Status and Plan in DMAG

CAPP-MAX → DMAG-12TB

1. Leiden fridge is being fixed!

2. Making HTS cavity stronger!

3. New and stronger HTS cavity will be ready!

Summary

- High Q-factor cavity boost axion scanning speed.
- Axion haloscope utilizing 12T/32cm bore magnet + Leiden dilution refrigerator can search DFSZ axions with reasonalble speed.
- CAPP's HTS cavities will enhance the axion scanning speed.
- Large size (>30L) HTS cavity is assembled for 1.2-1.5 GHz and the Q-factor of the cavity is around 10^6 in the 11.2 tesla magnetic field
- DMAG will keep going with HTS cavites.