ORGAN Phase 1B: Results and Future Plans

THE UNIVERSITY OF WESTERN AUSTRALIA

Aaron Quiskamp

EQUS
Australian Research Council Centre of Excellence for Engineered Quantum Systems

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

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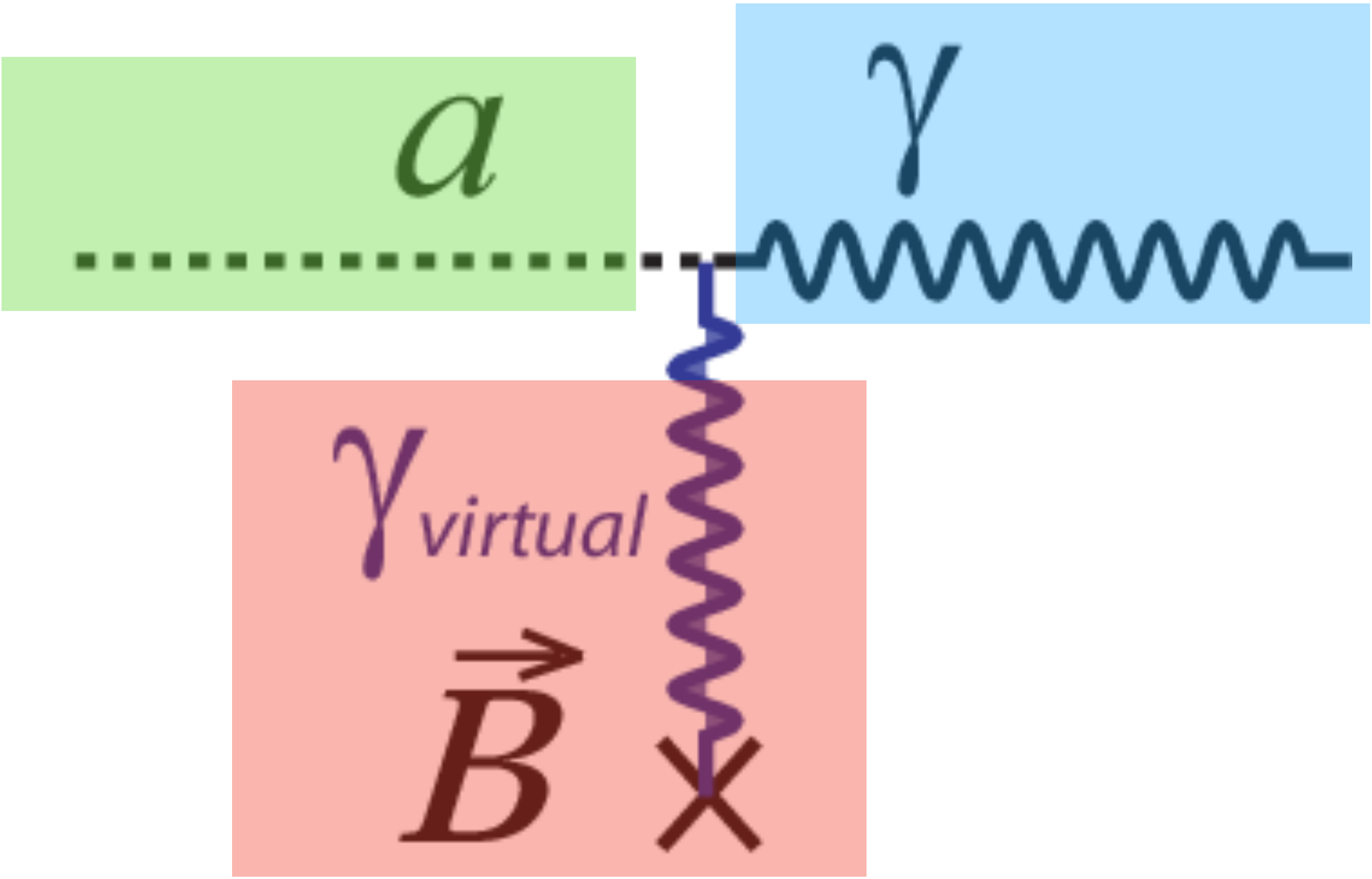
- The **strong CP problem** and the **dark matter problem**
- Axions may interact with a strong **B** field to produce a photon with frequency related to m_a



Inverse Primakoff effect

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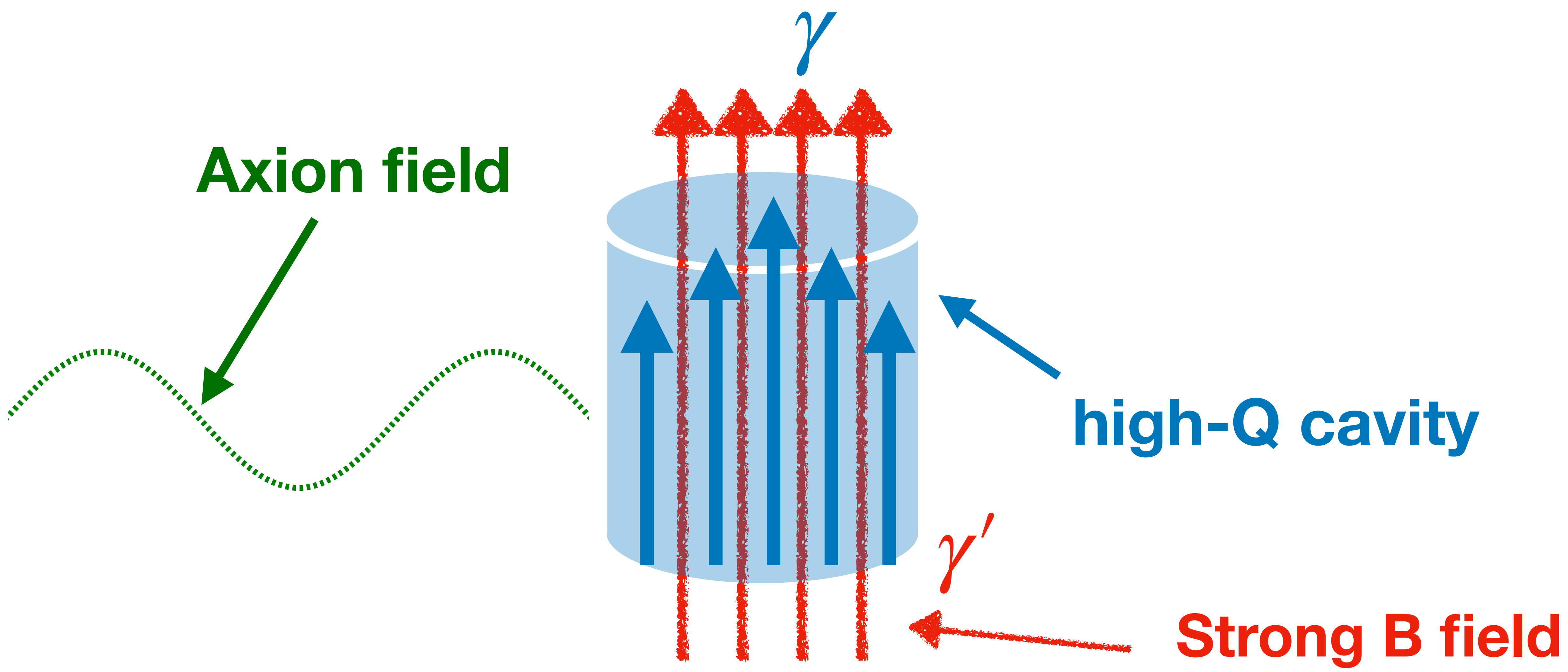

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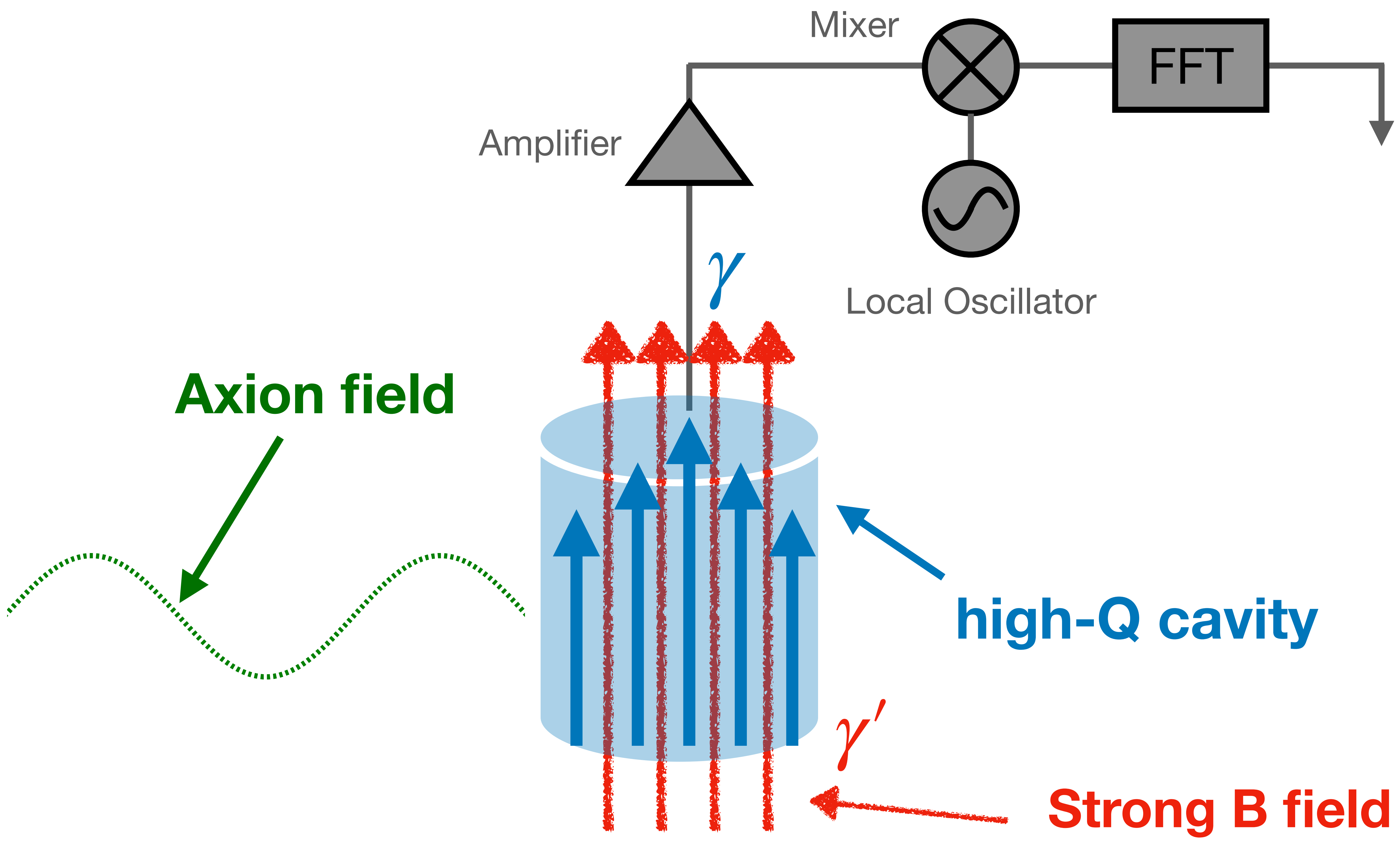

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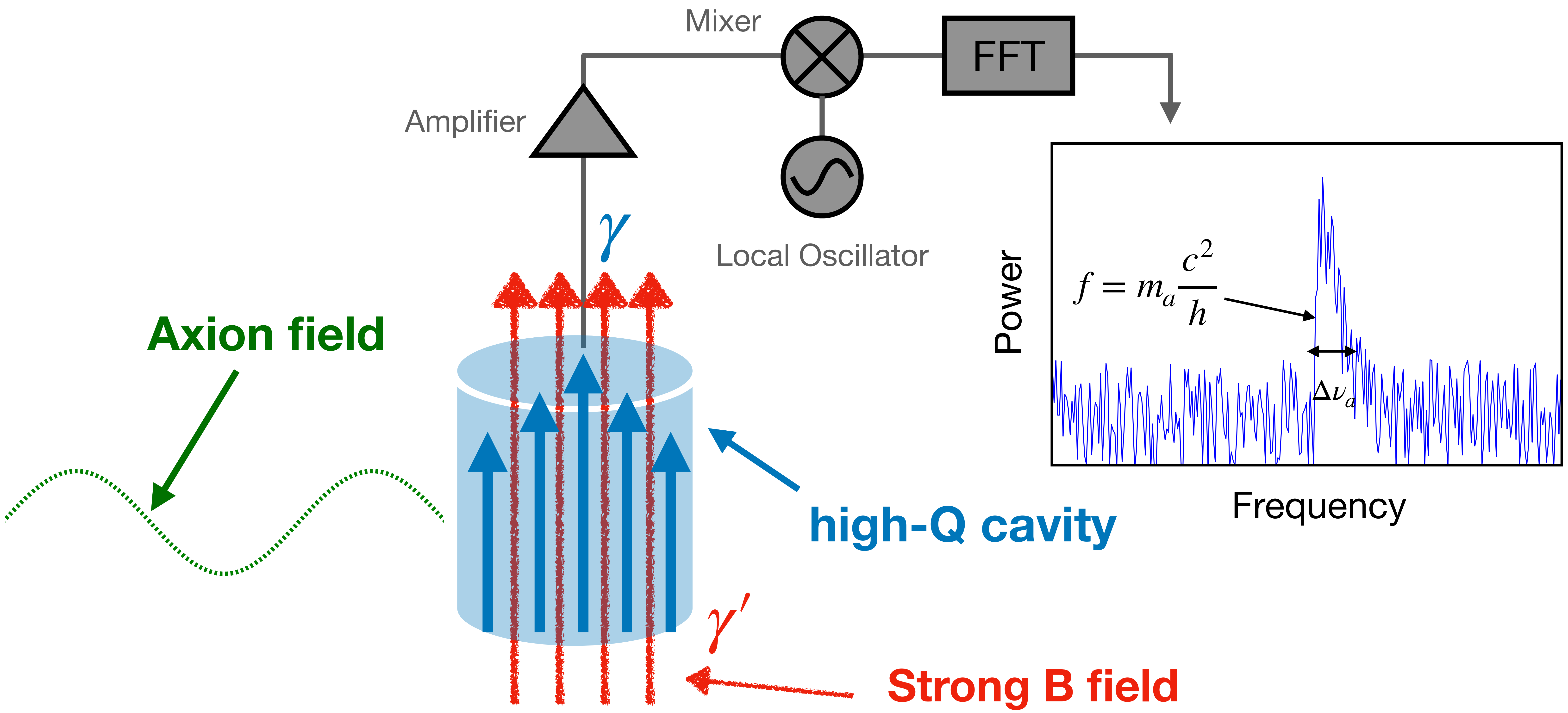

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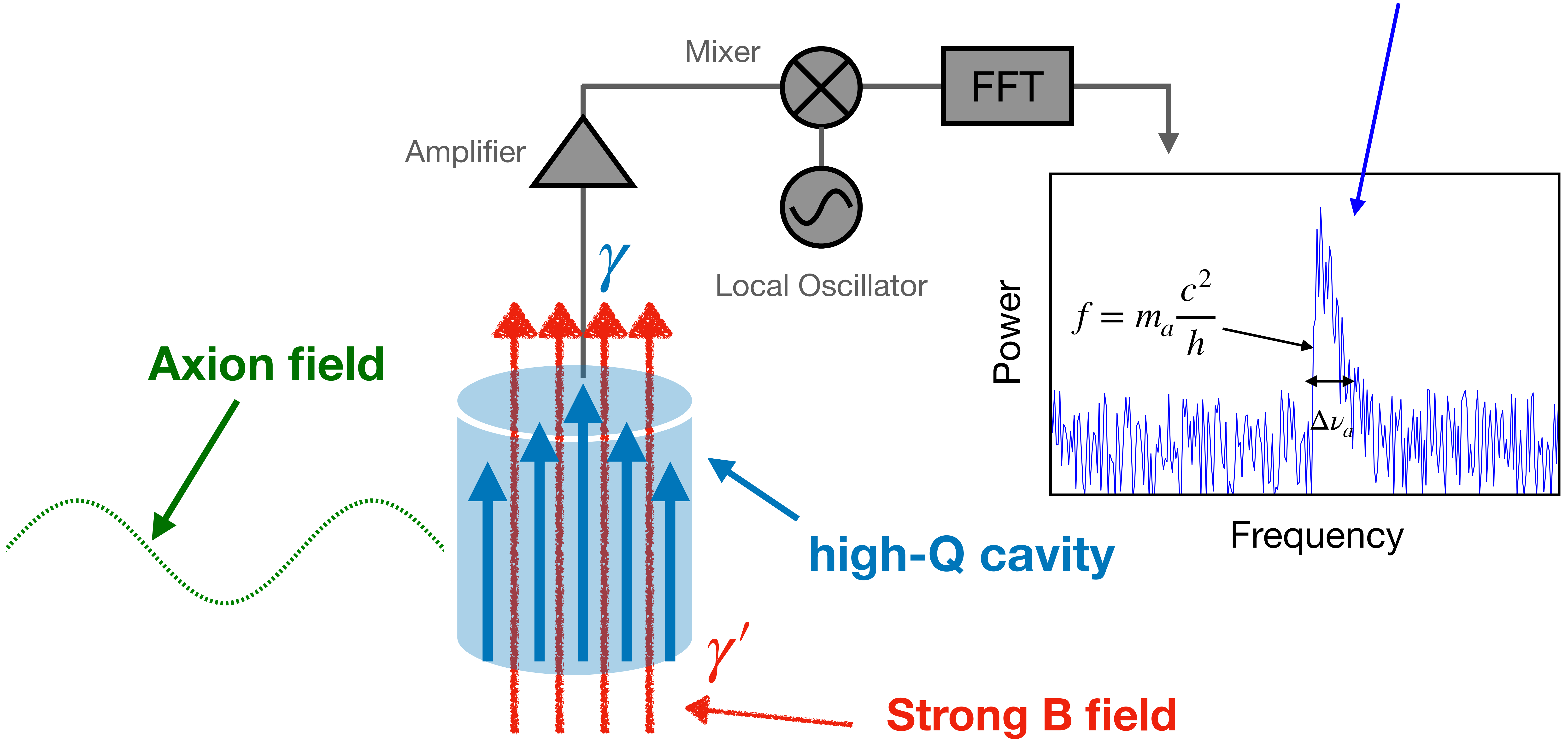

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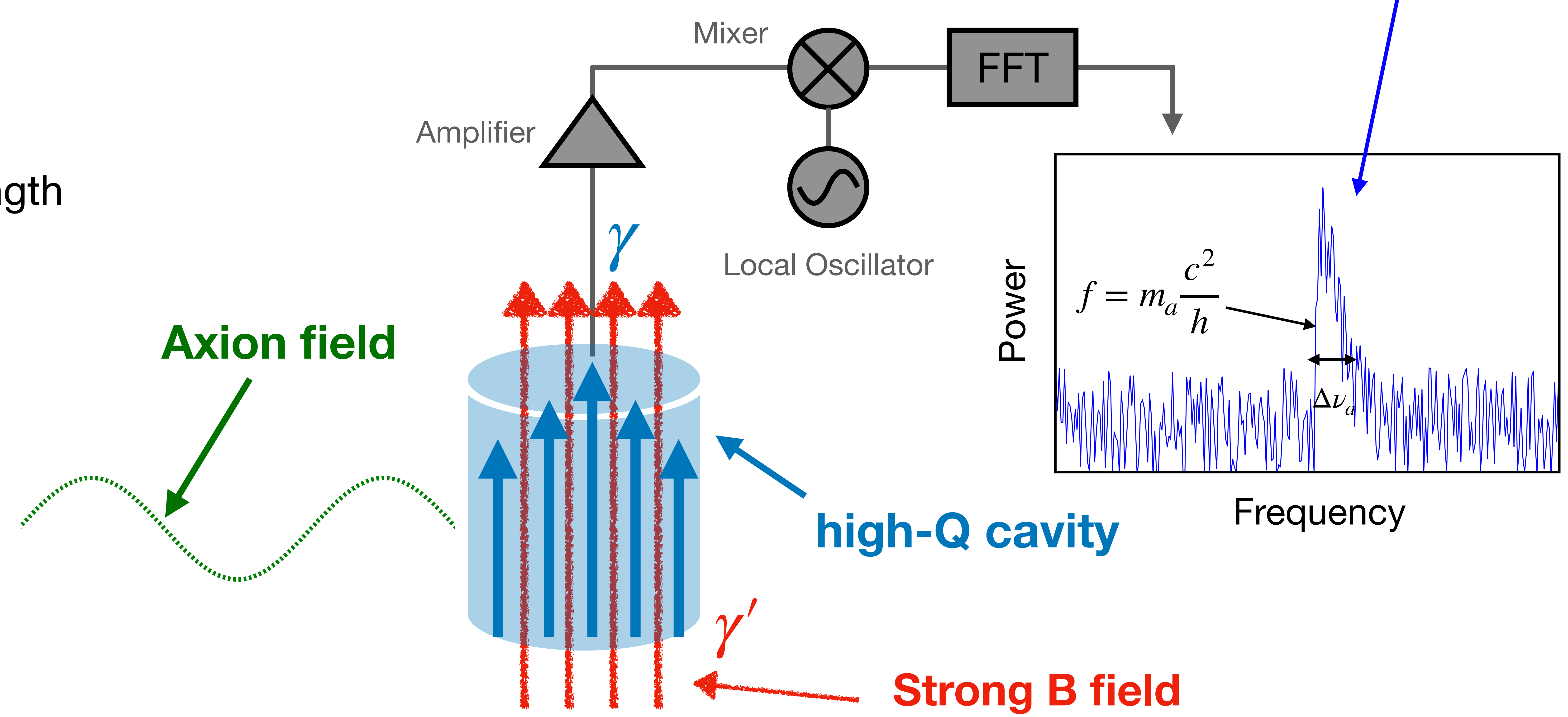

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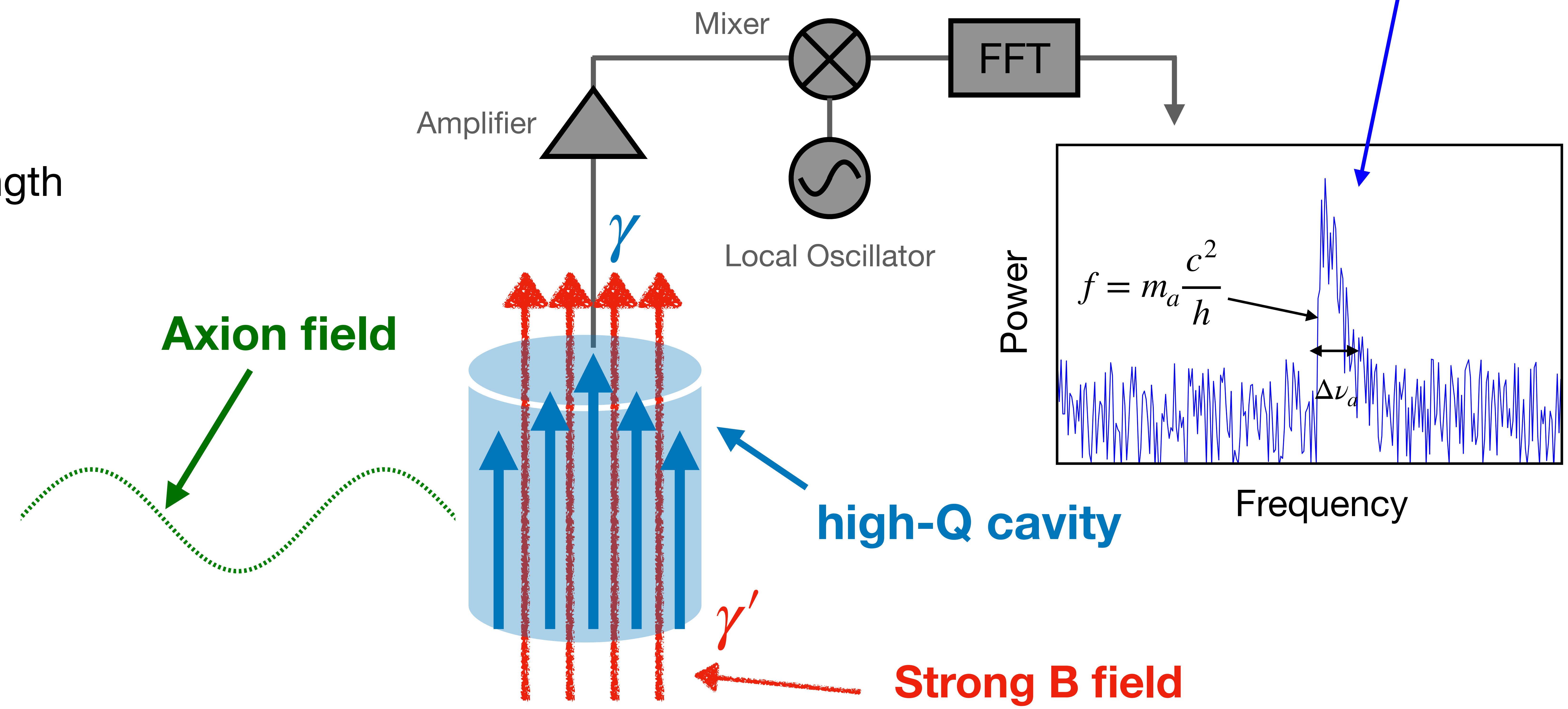

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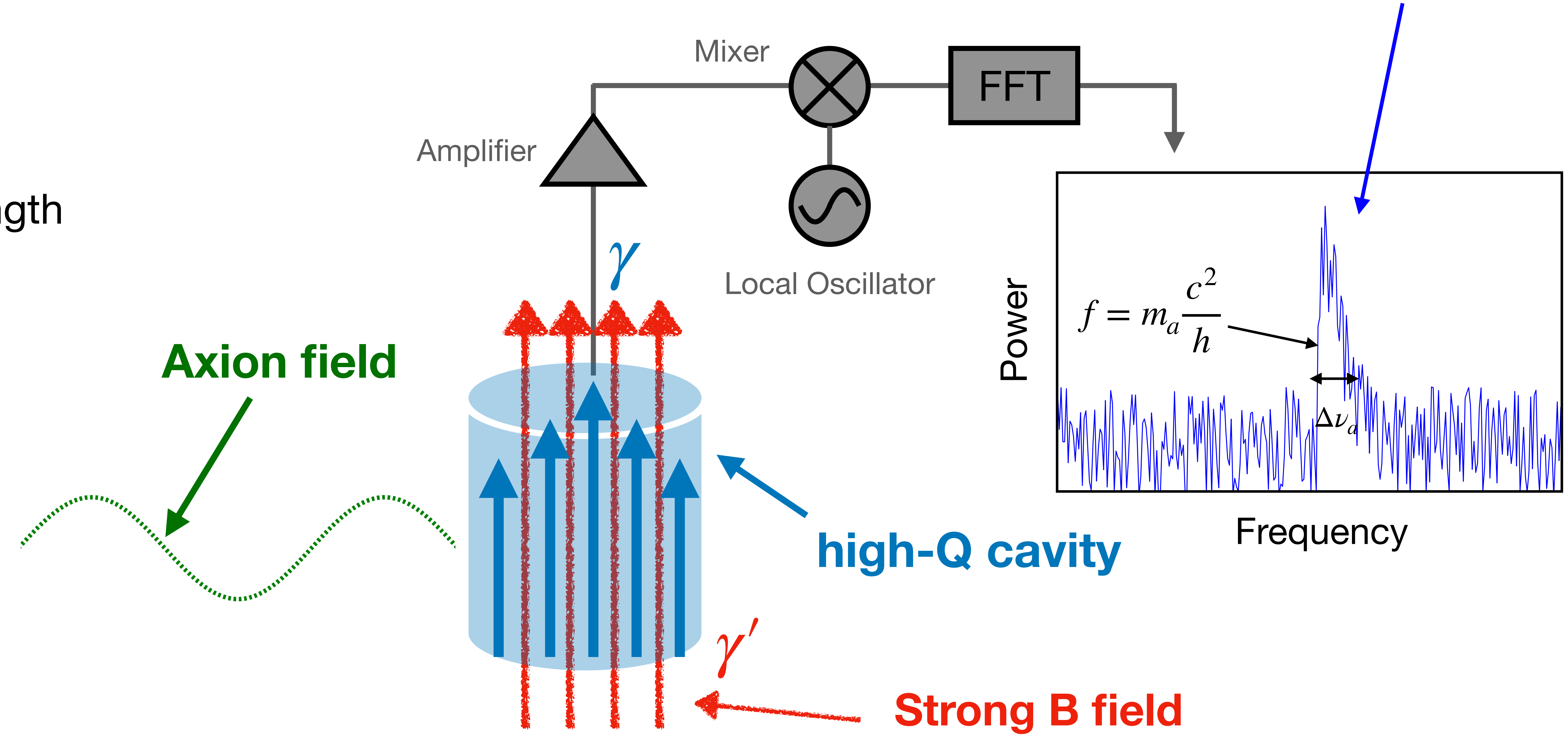

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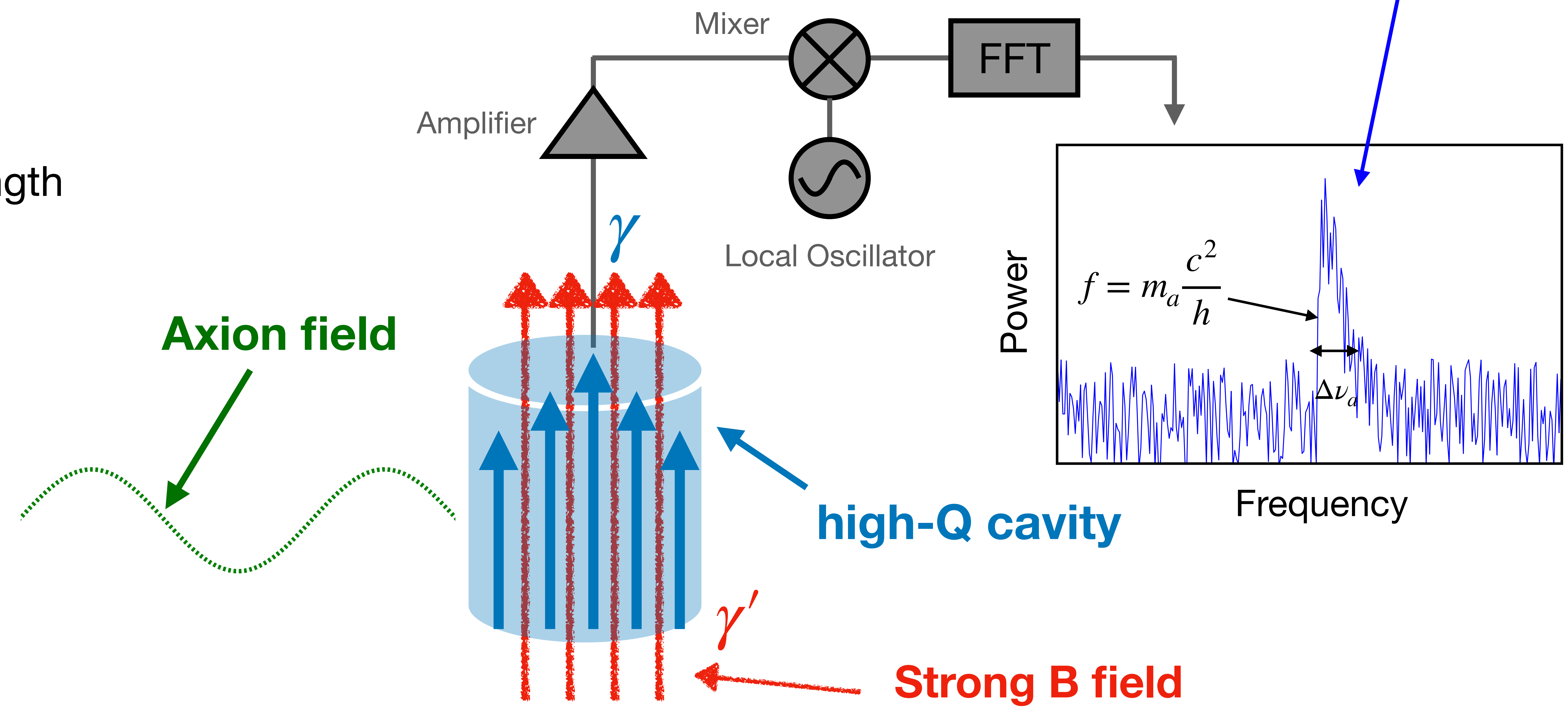

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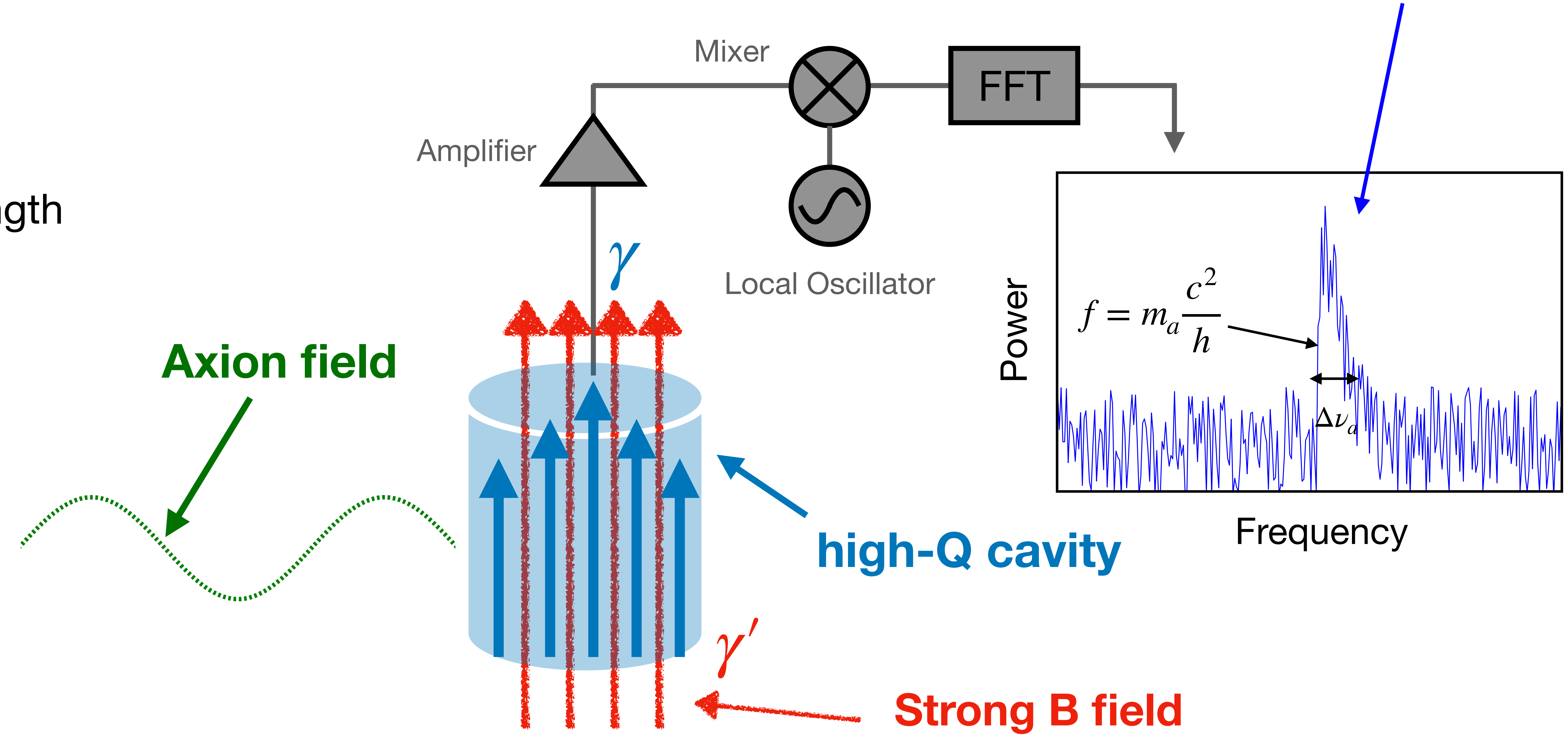

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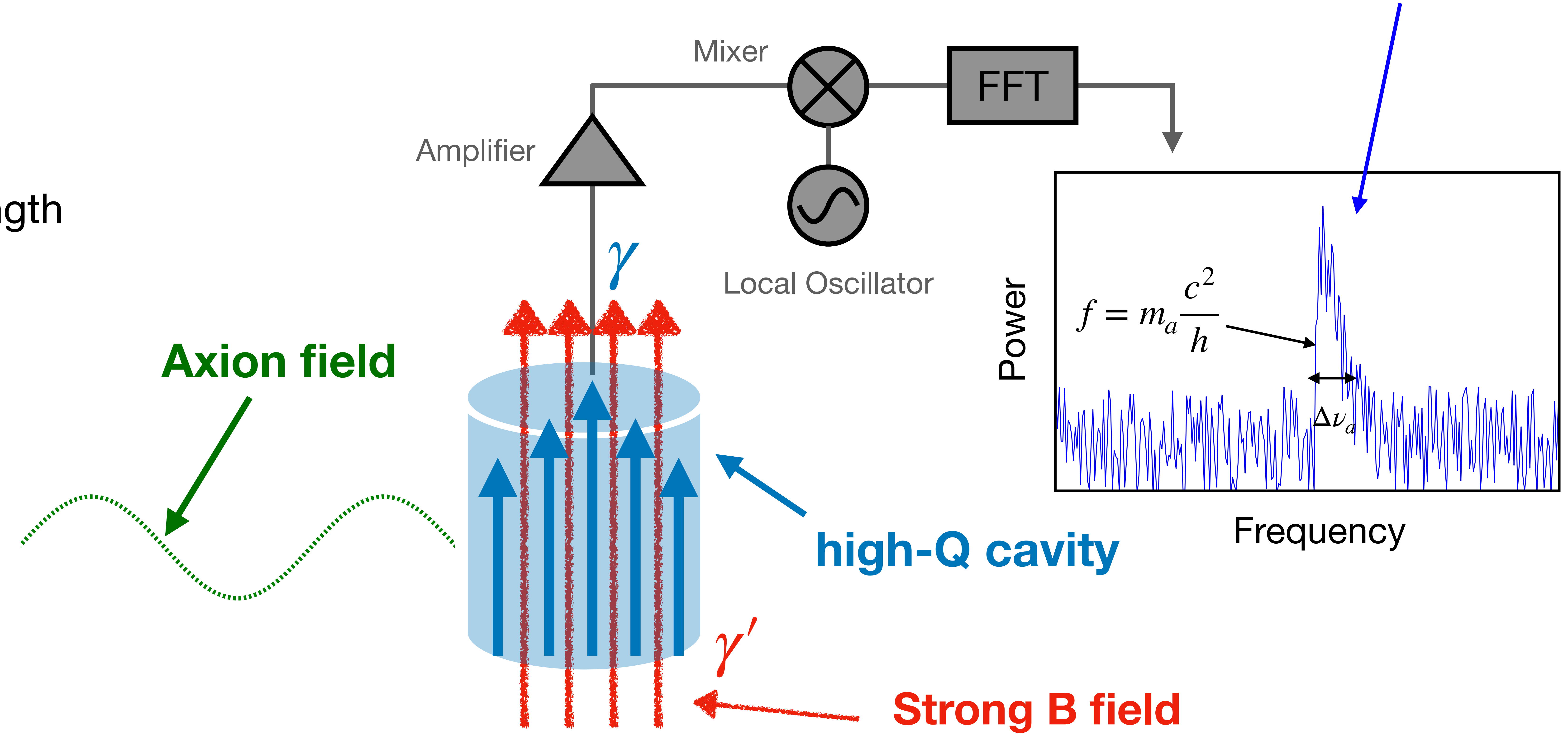

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Focus on increasing **this**

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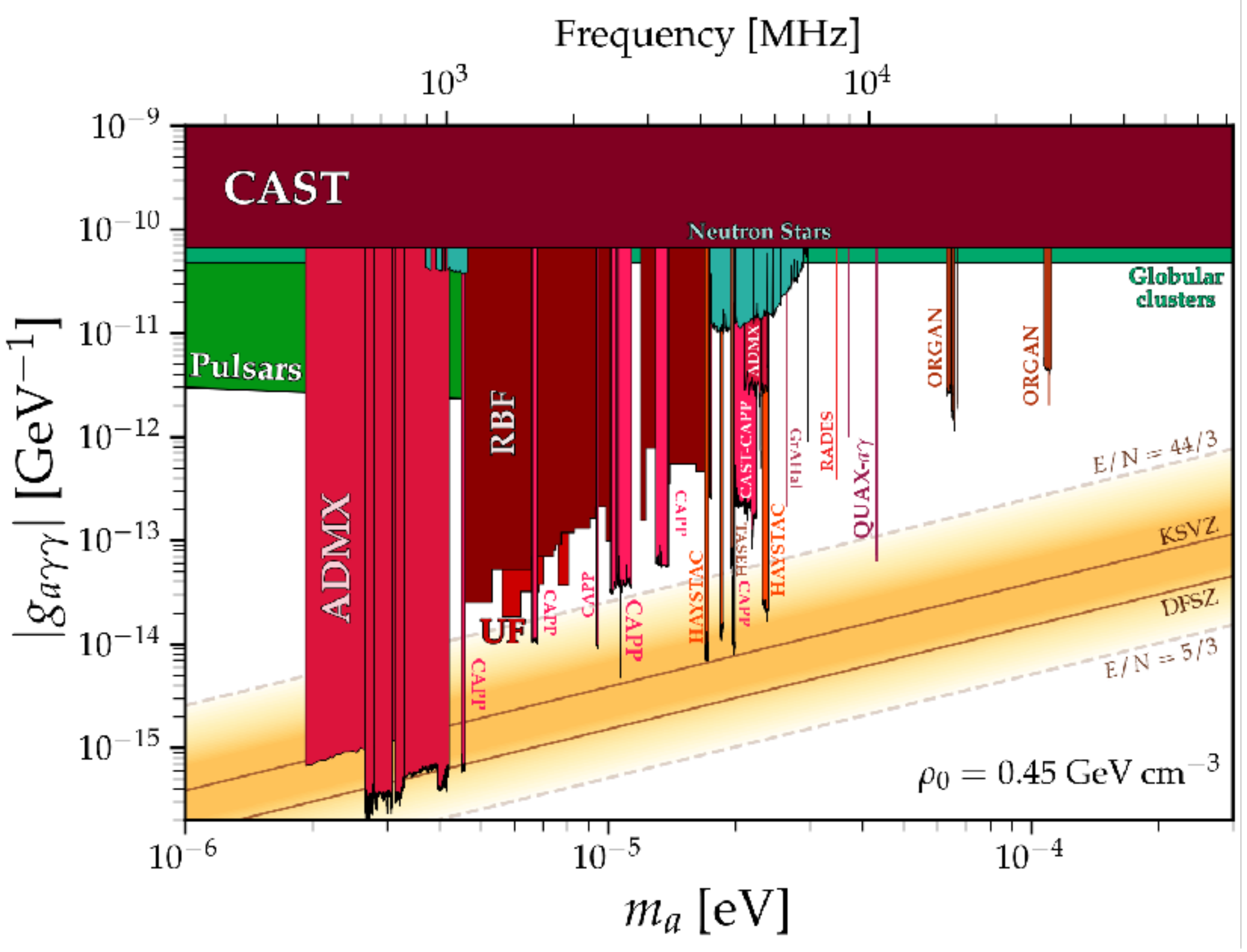

cajohare.github.io/

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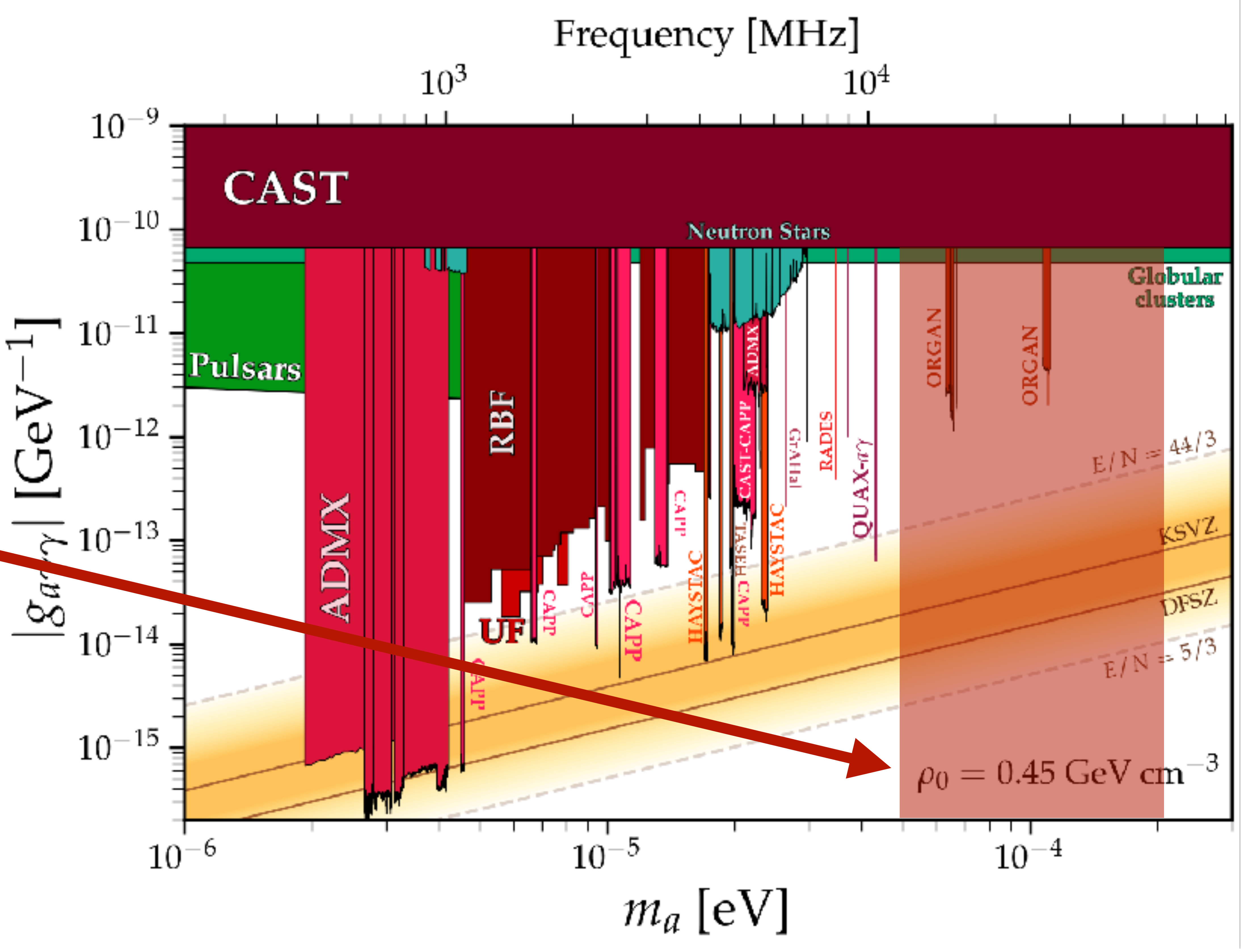

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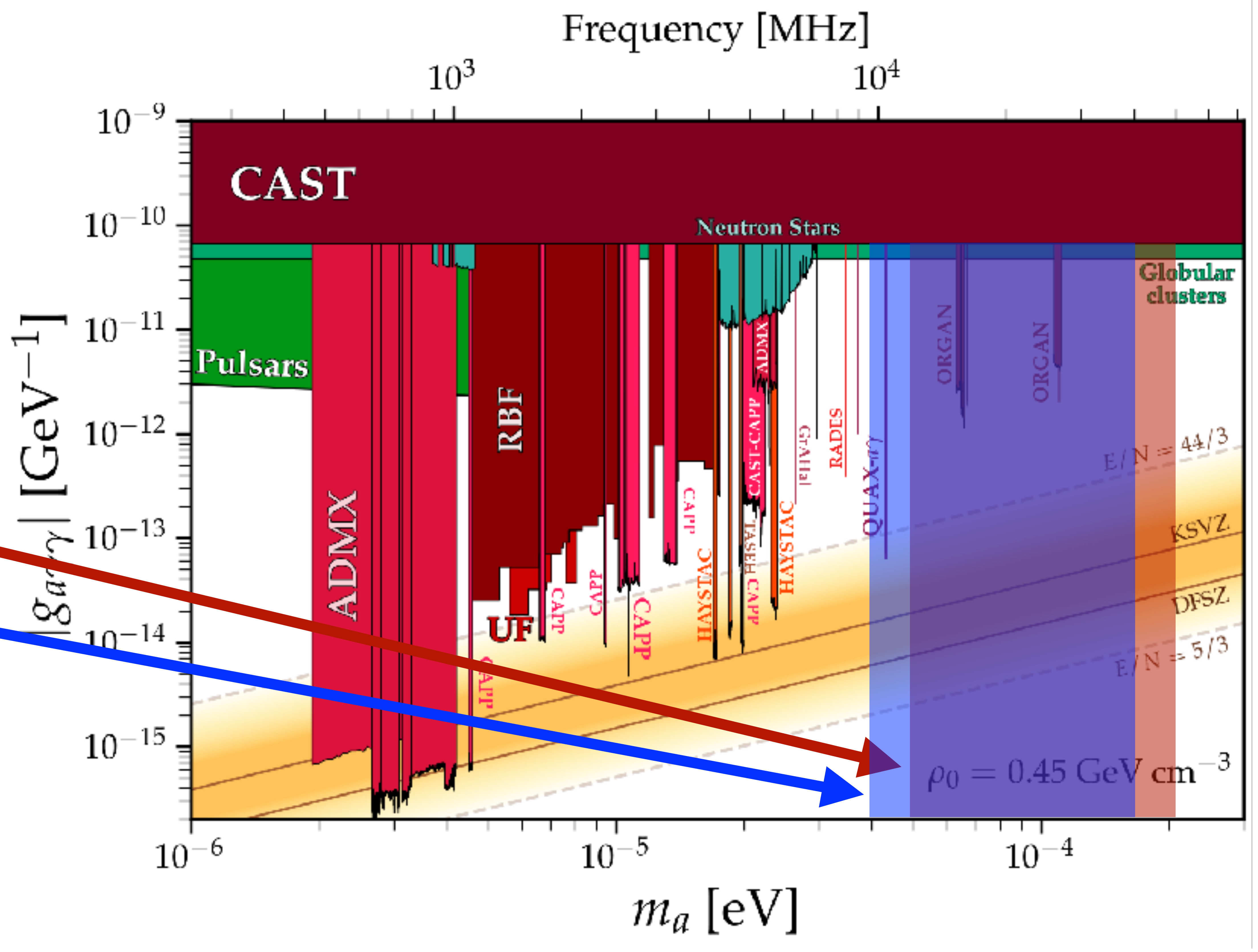

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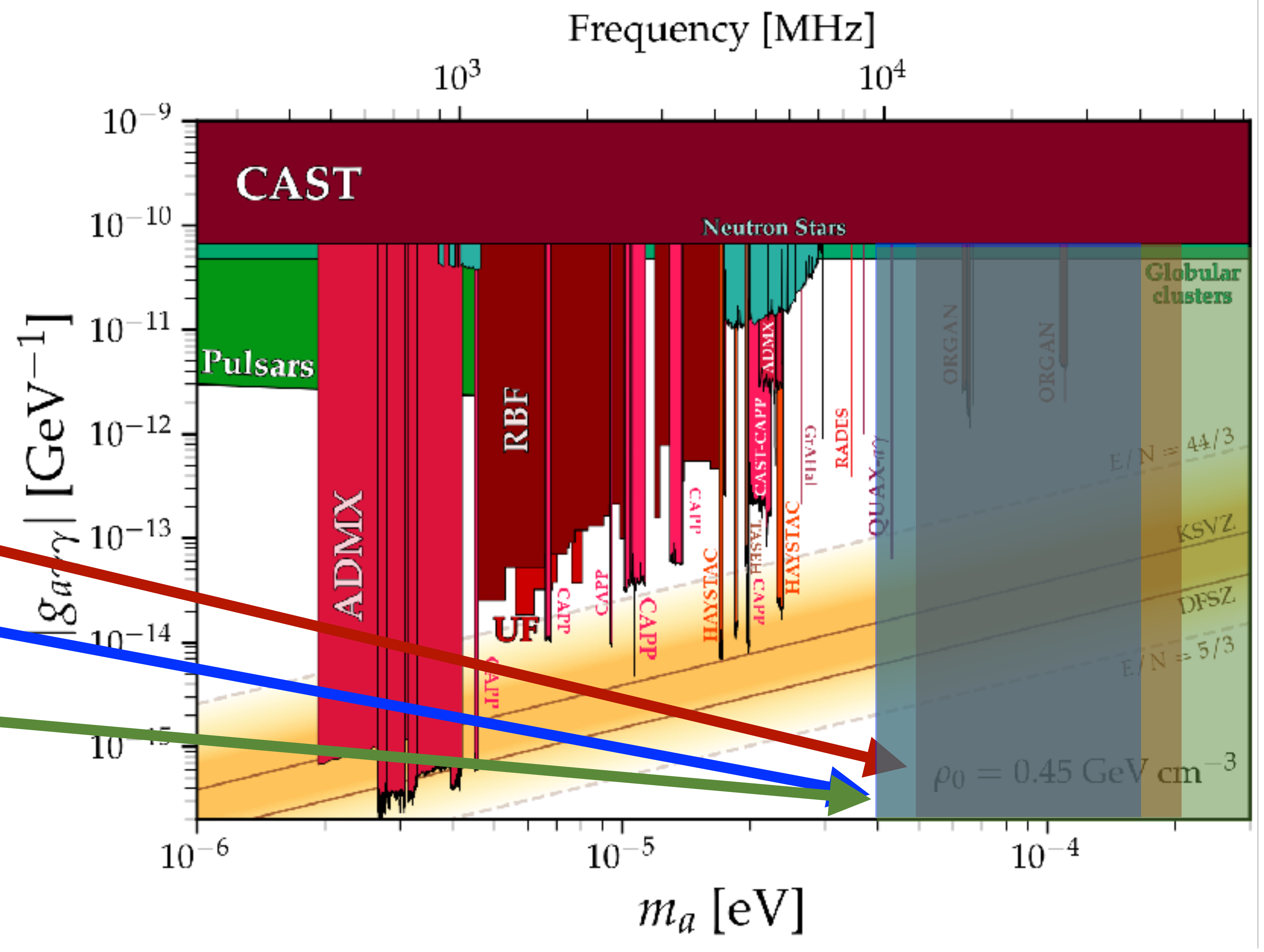

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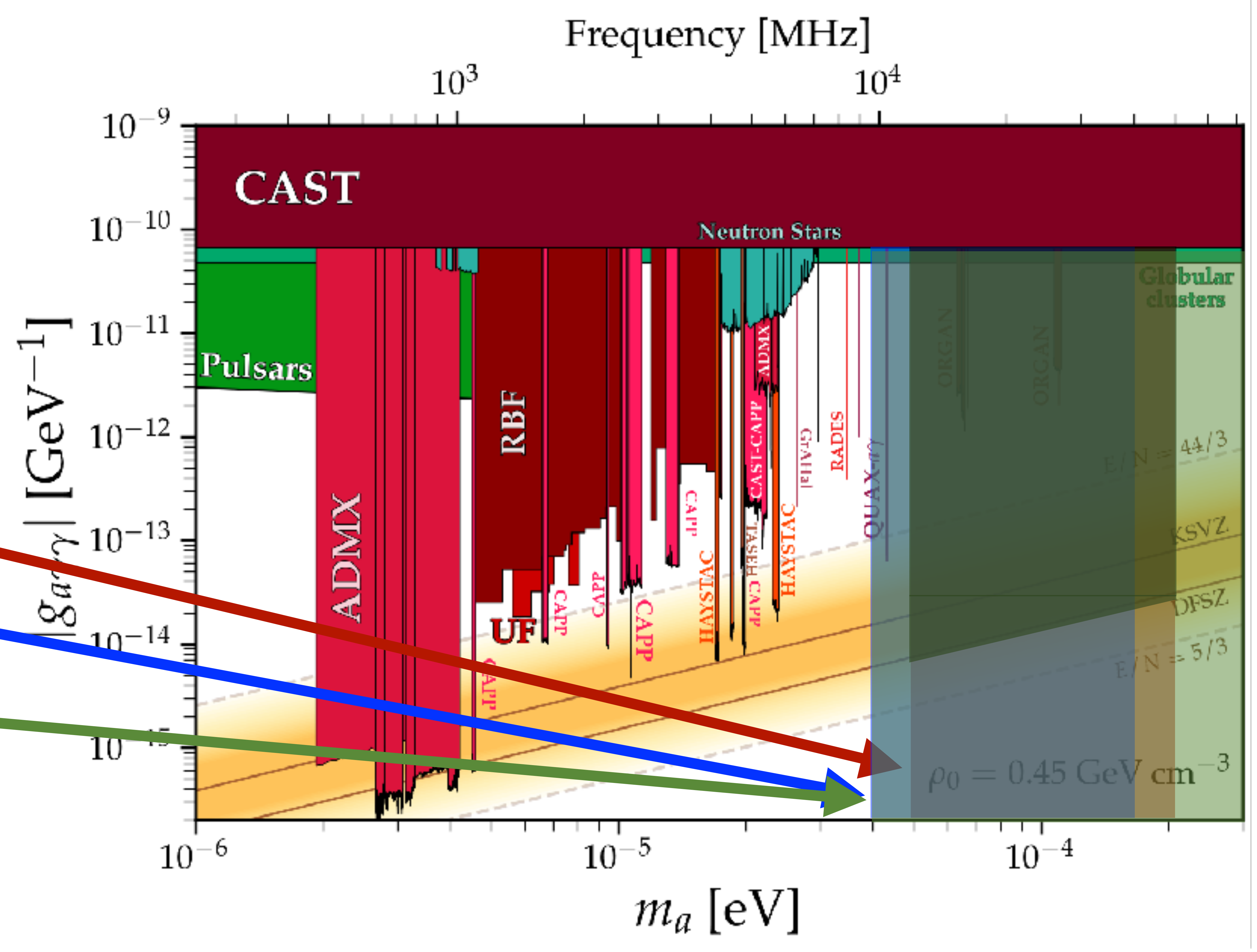

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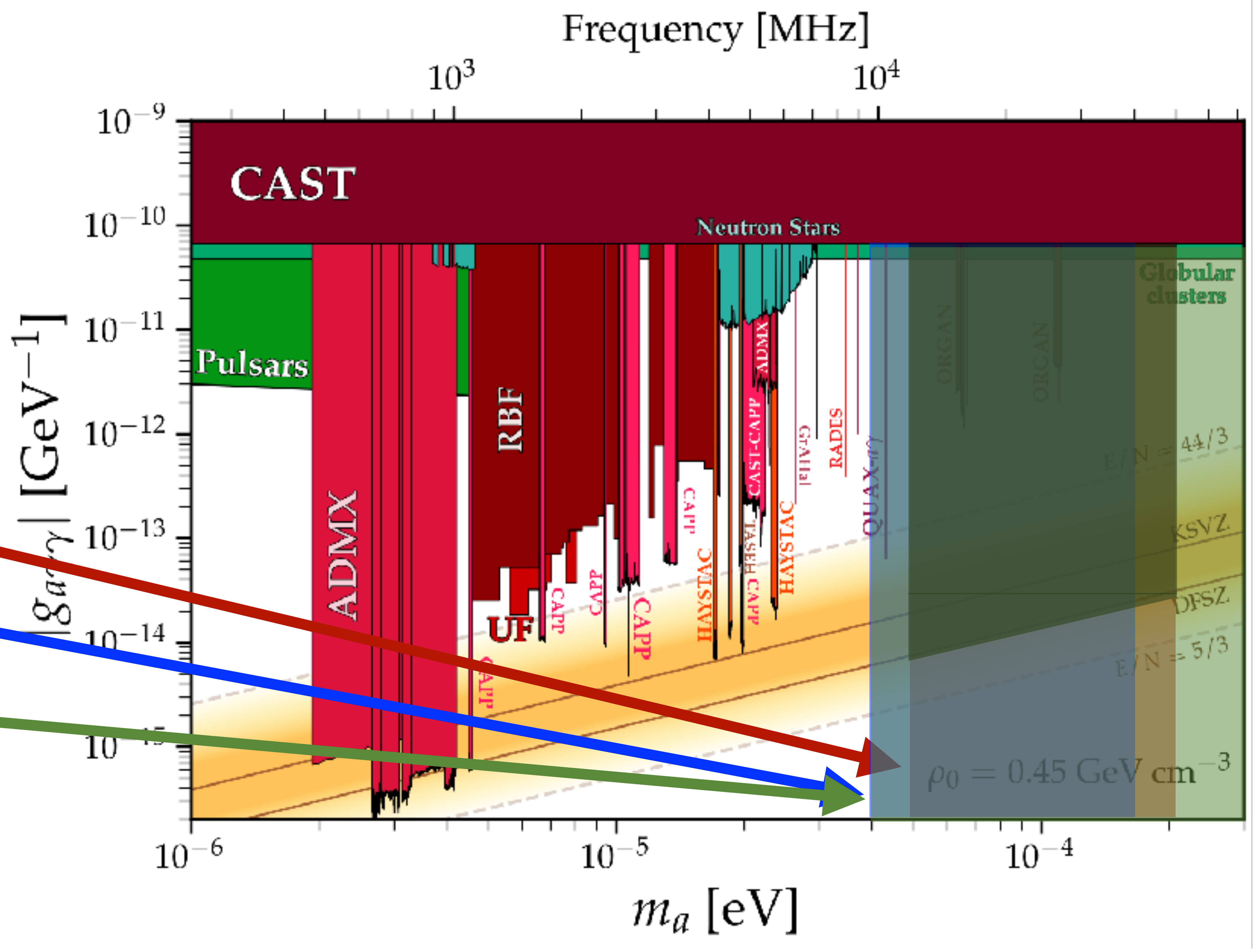
- $\frac{df}{dt} \propto f^{-14/3}$ → High frequency (mass) scales poorly



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Phase 1a

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- Scan between 15-16 GHz

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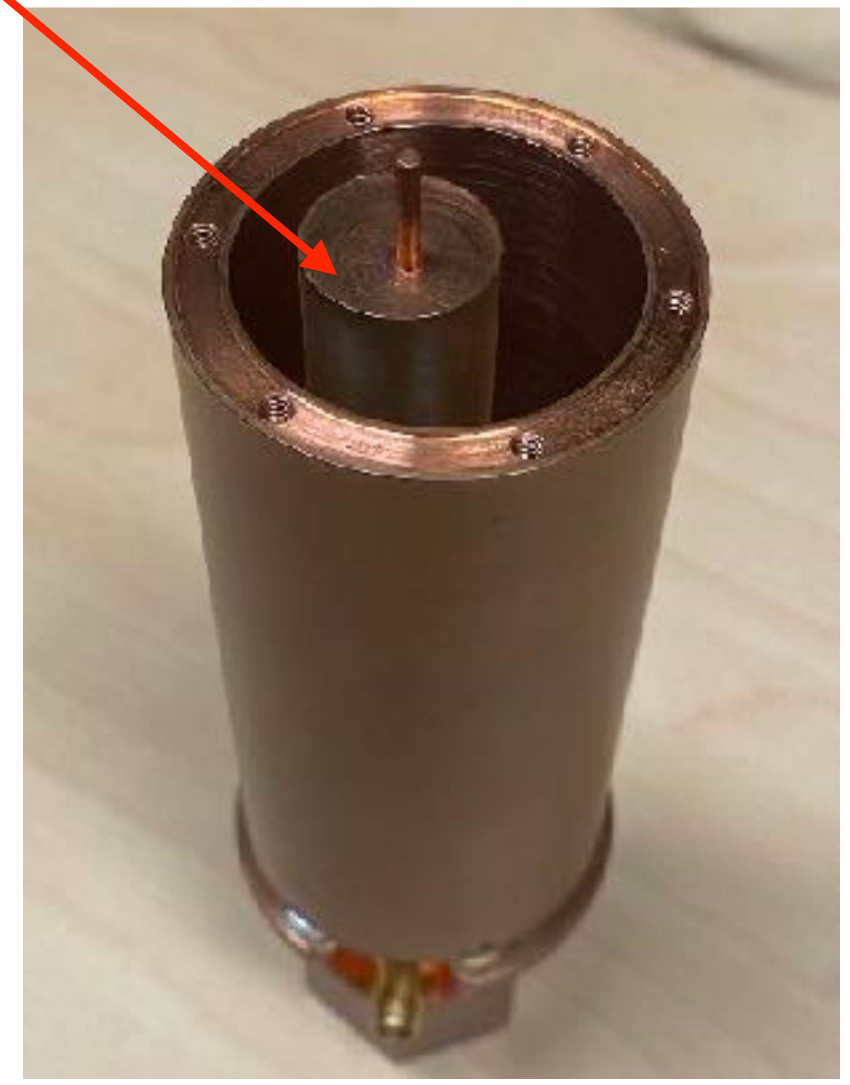
Tuning rod



Rotation stage

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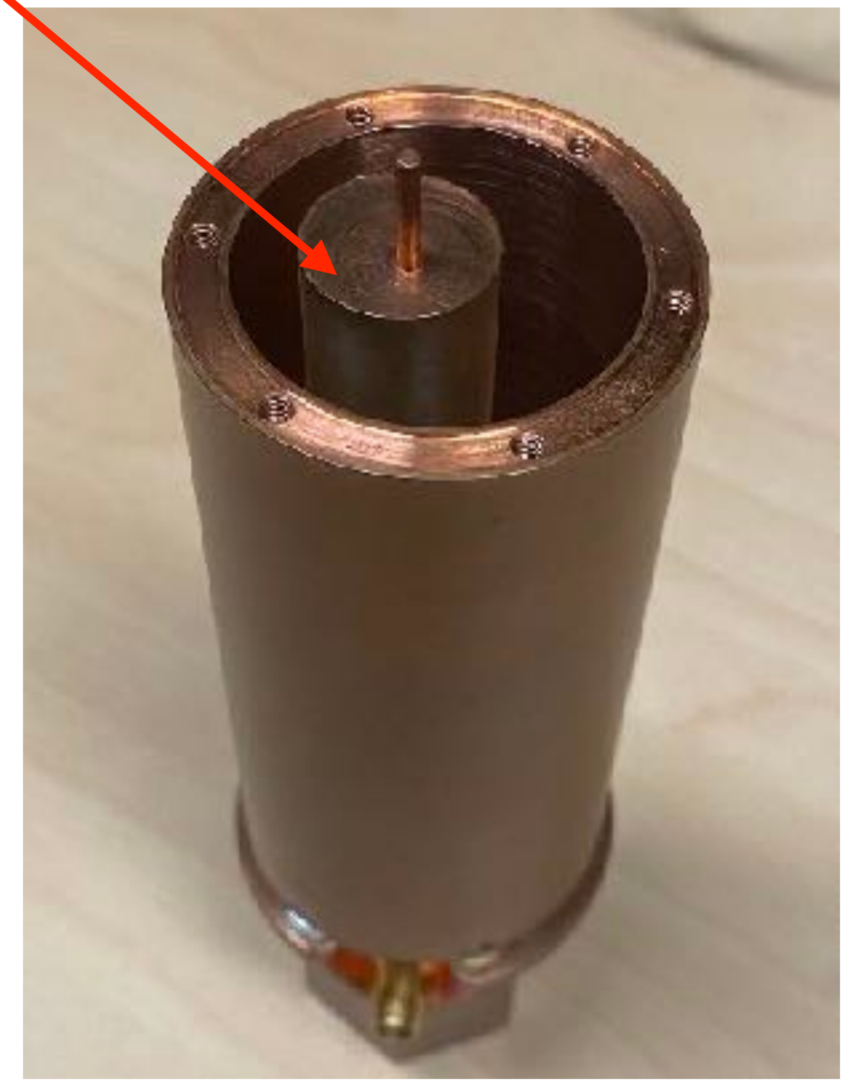

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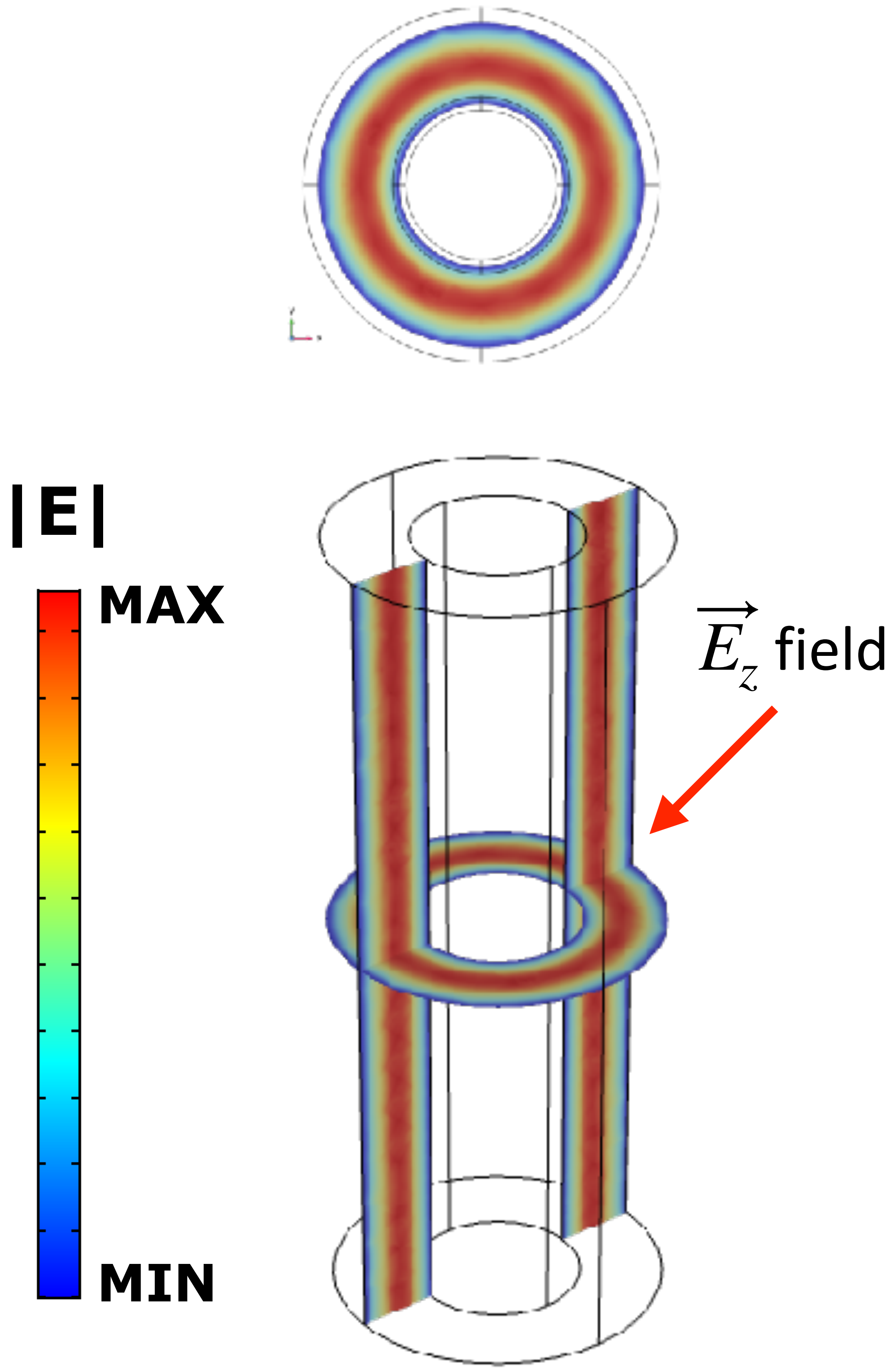

TM_{010} mode

Phase 1a

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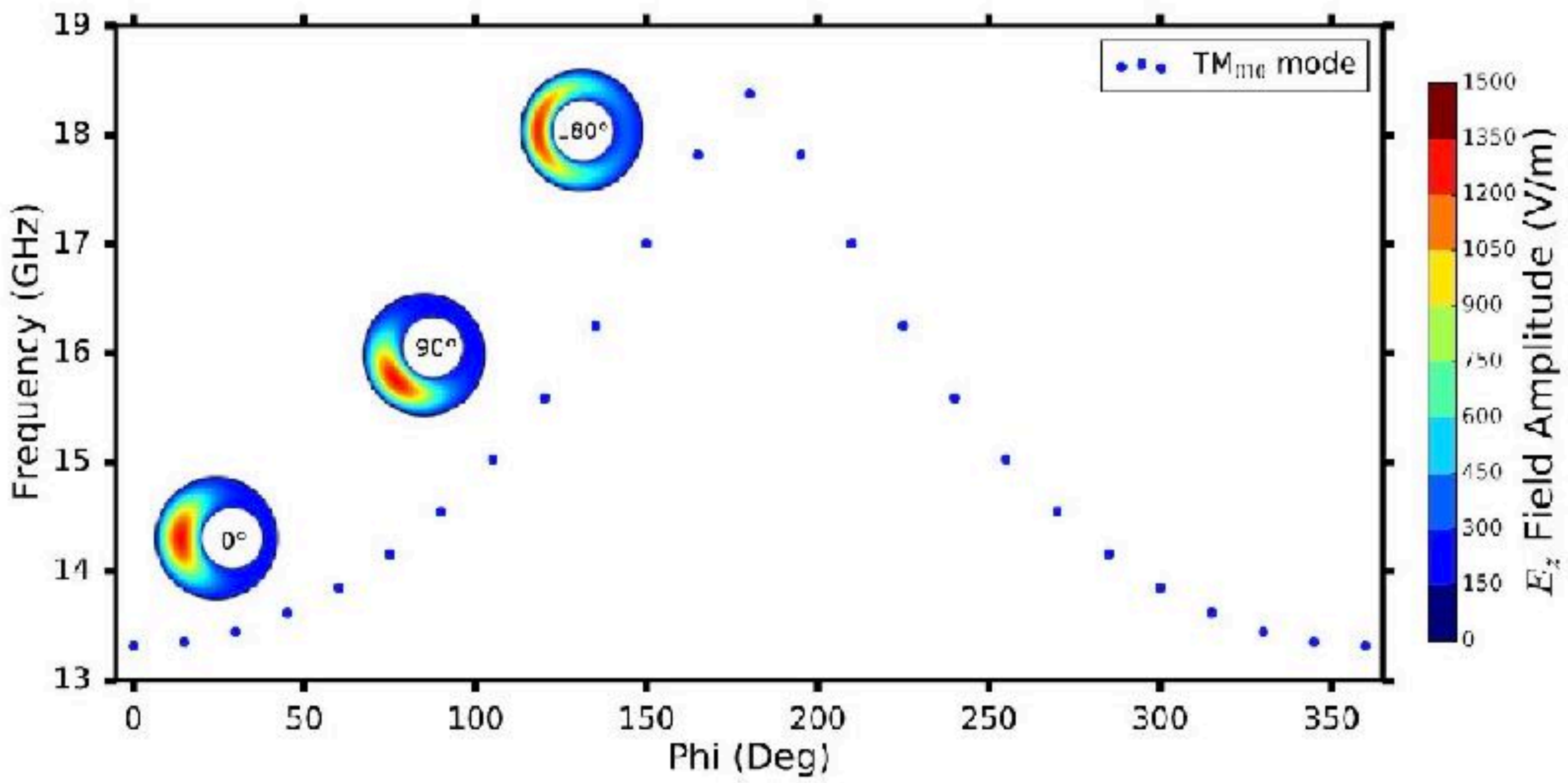
- **Tuning:** moving the rod radially perturbs the axion sensitive mode, shifting the frequency



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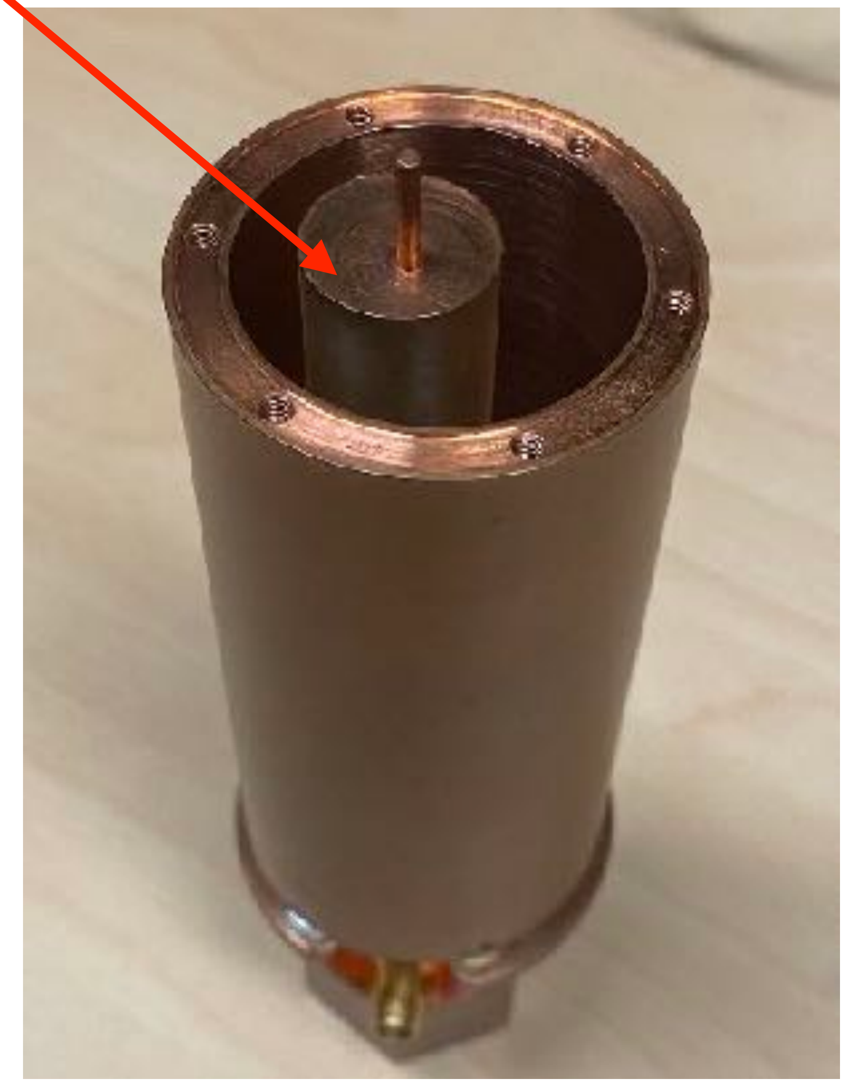

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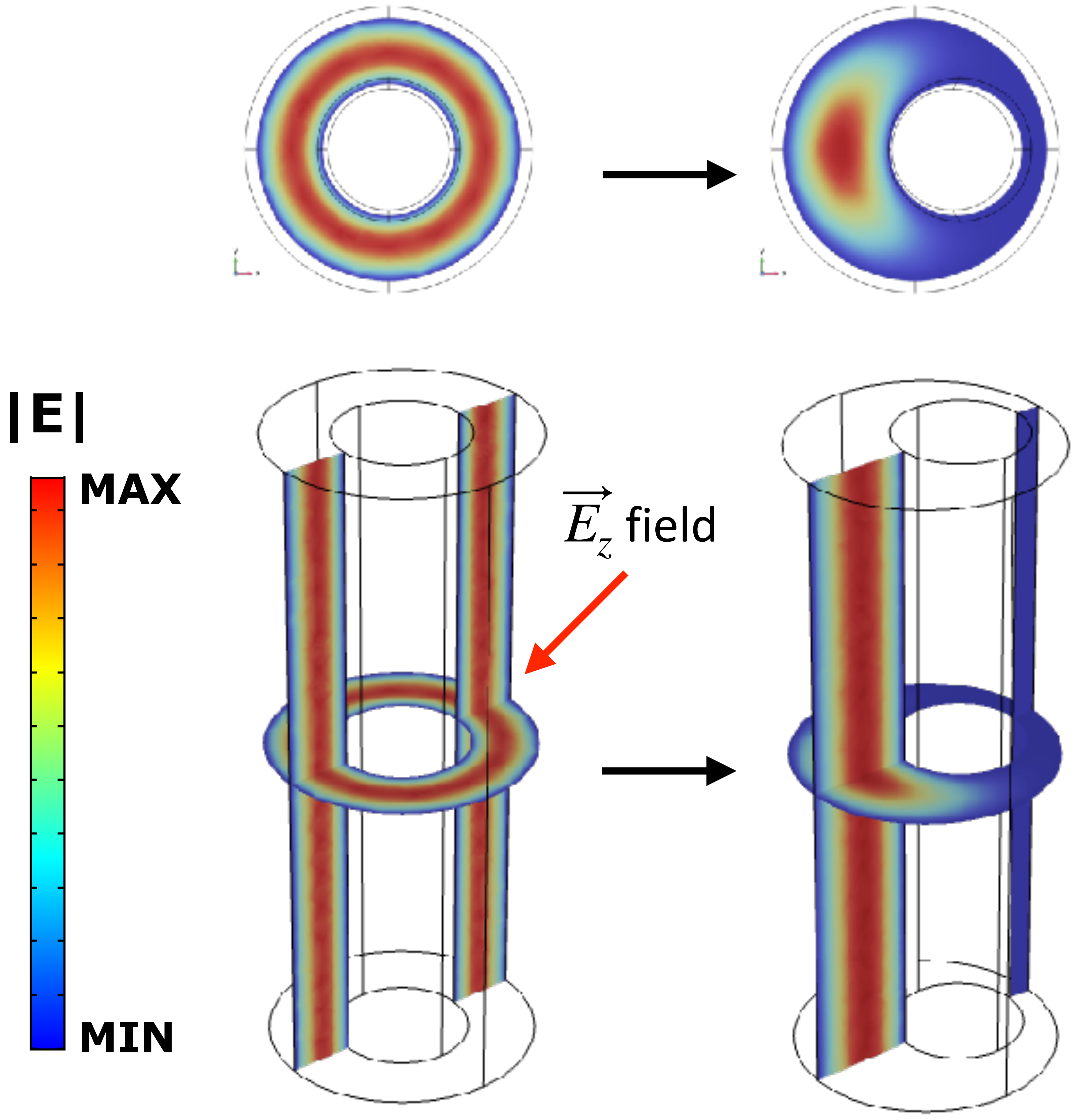

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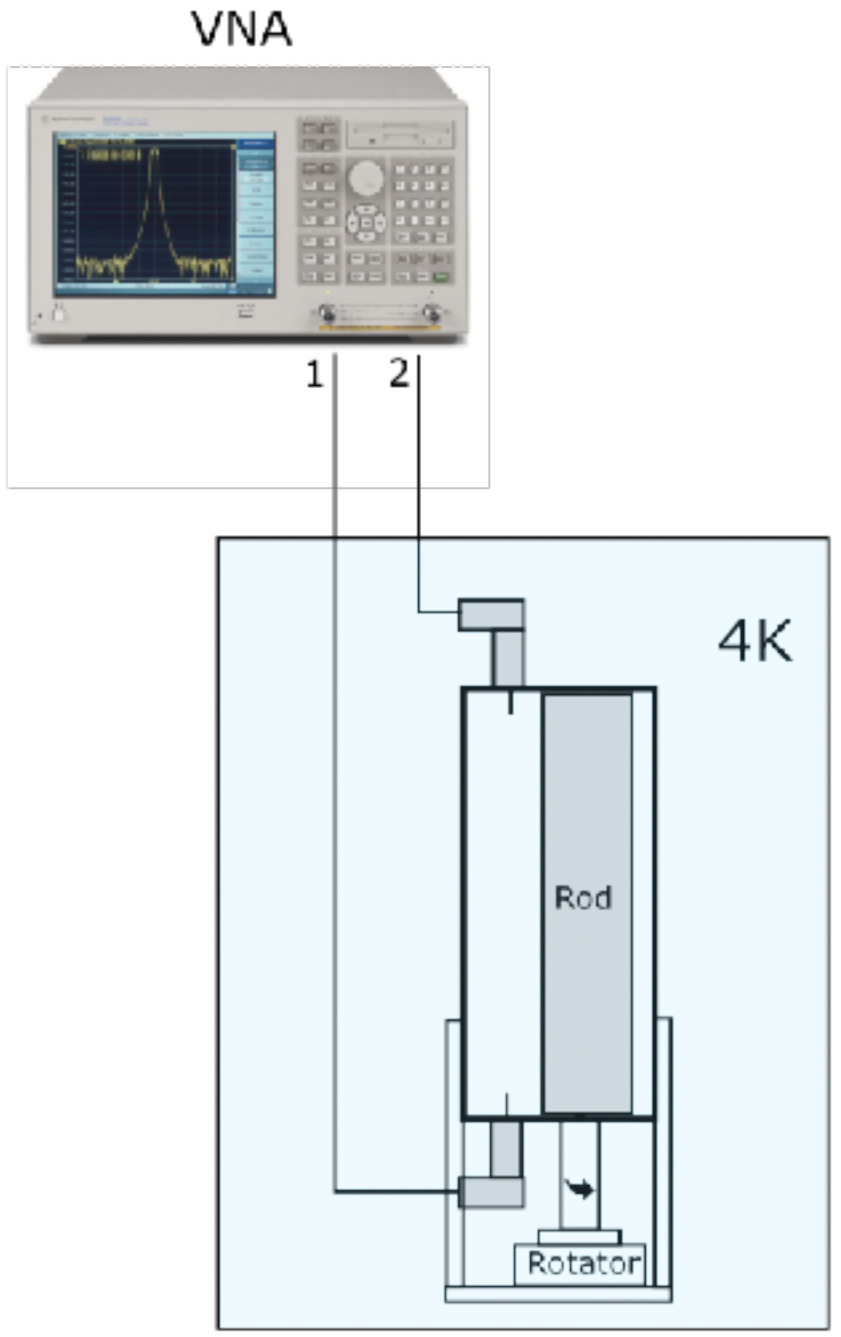

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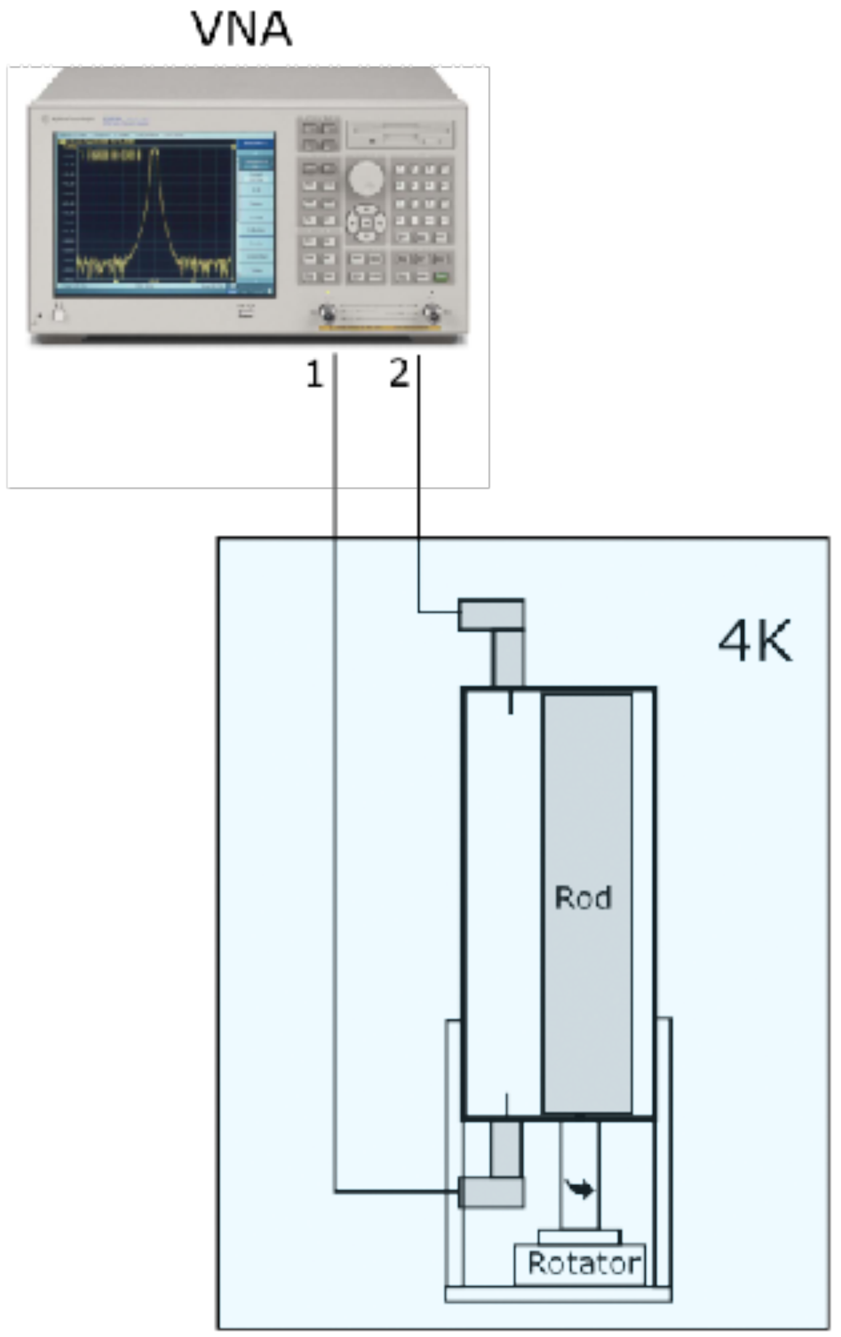

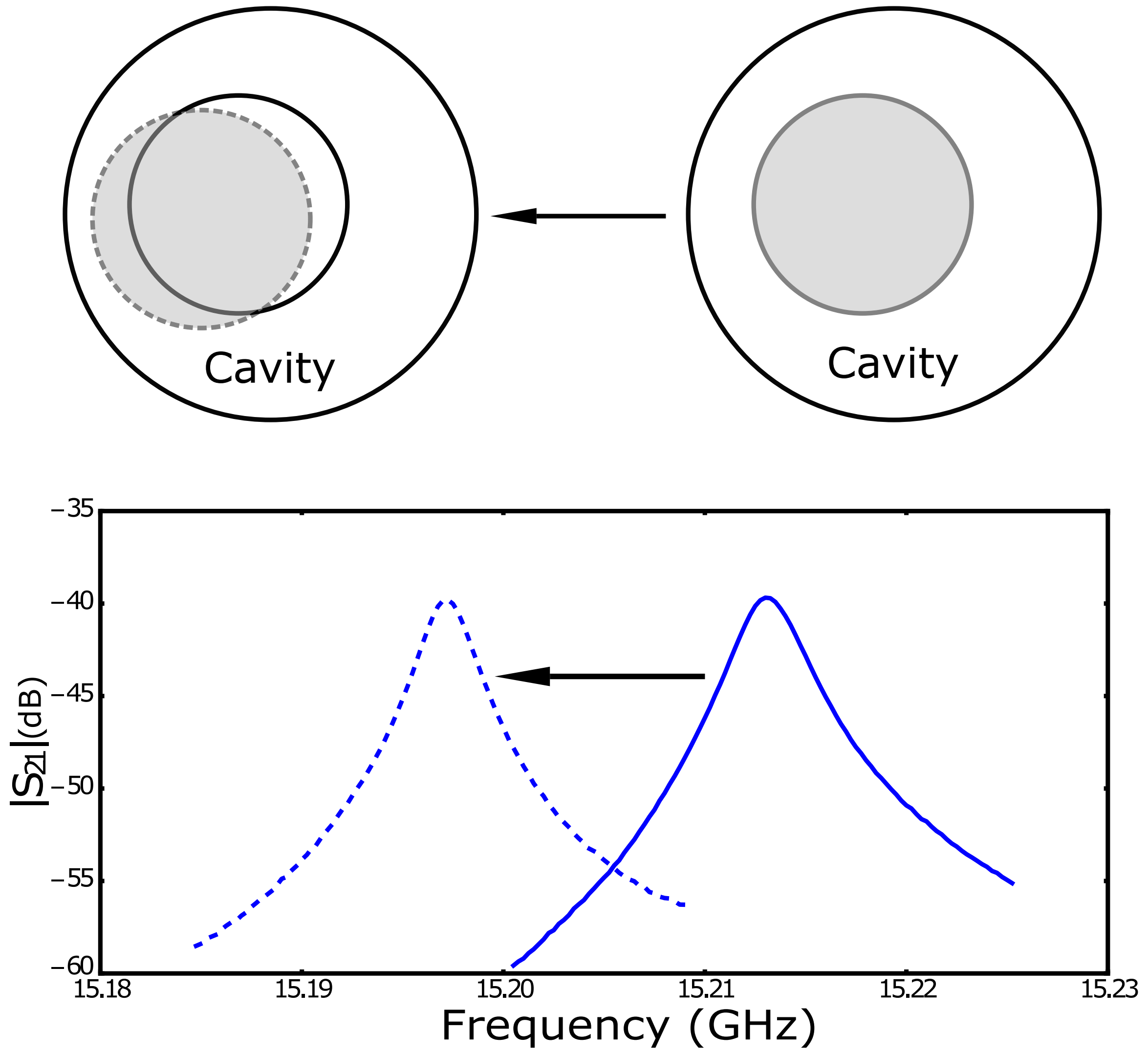

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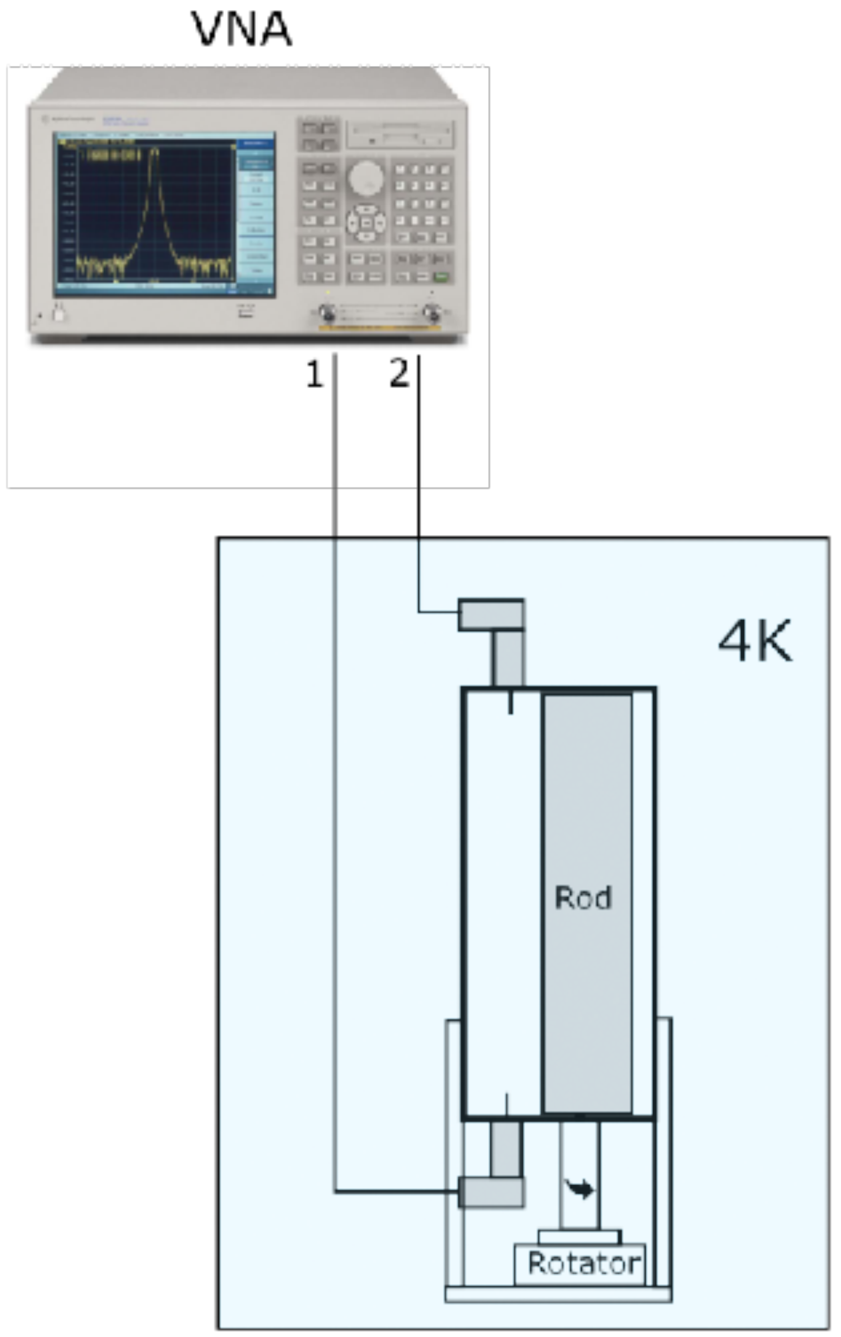
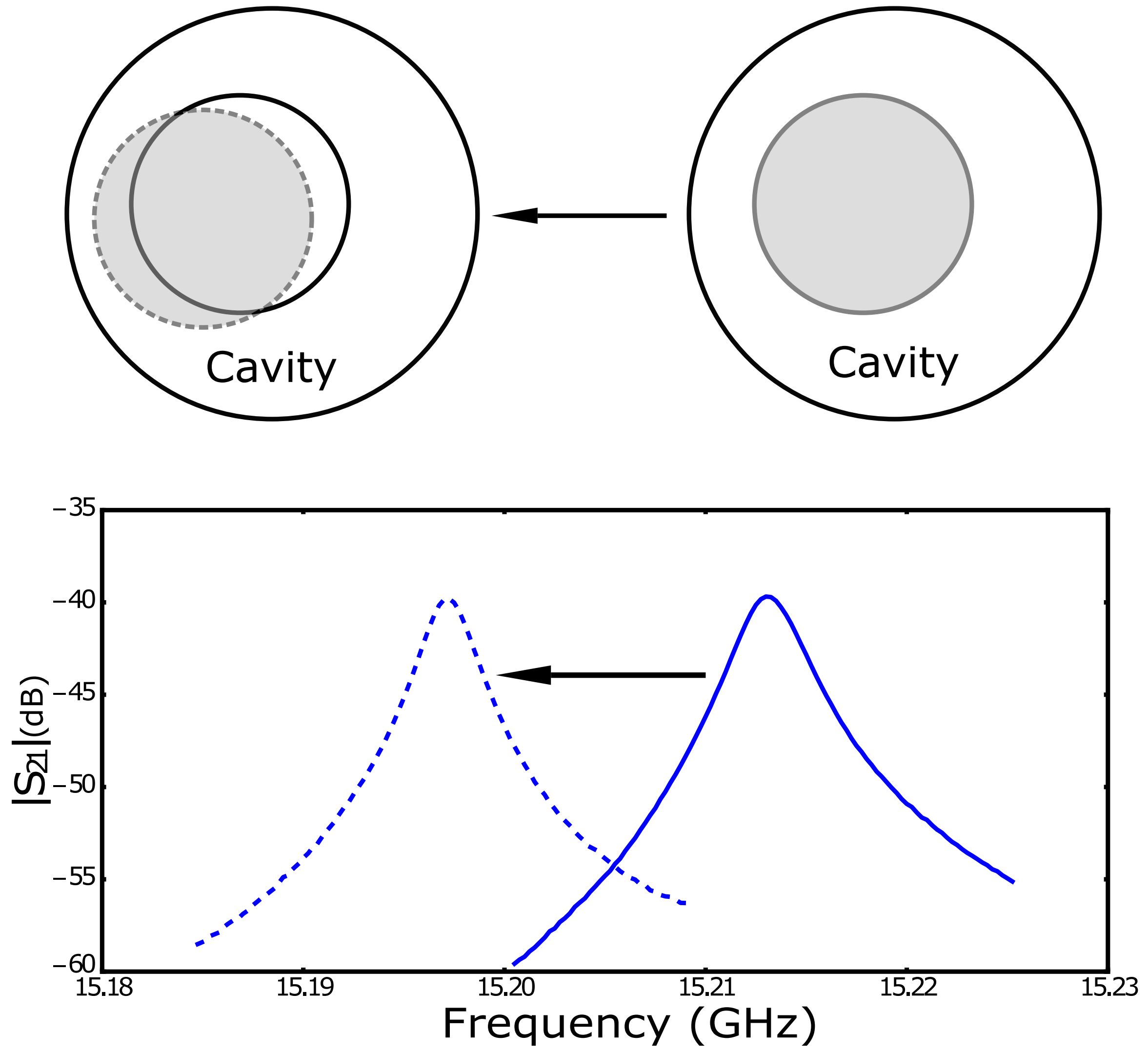
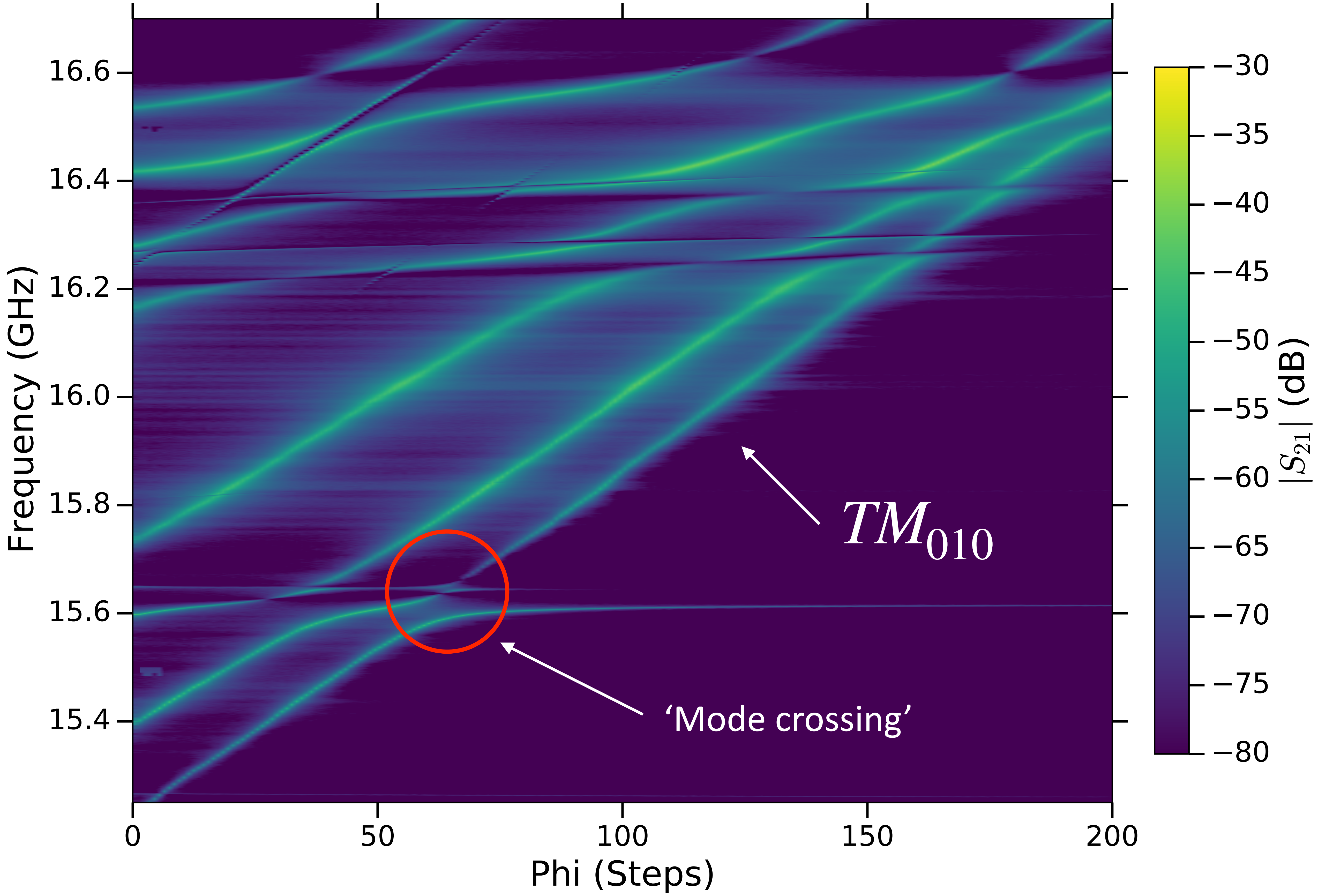




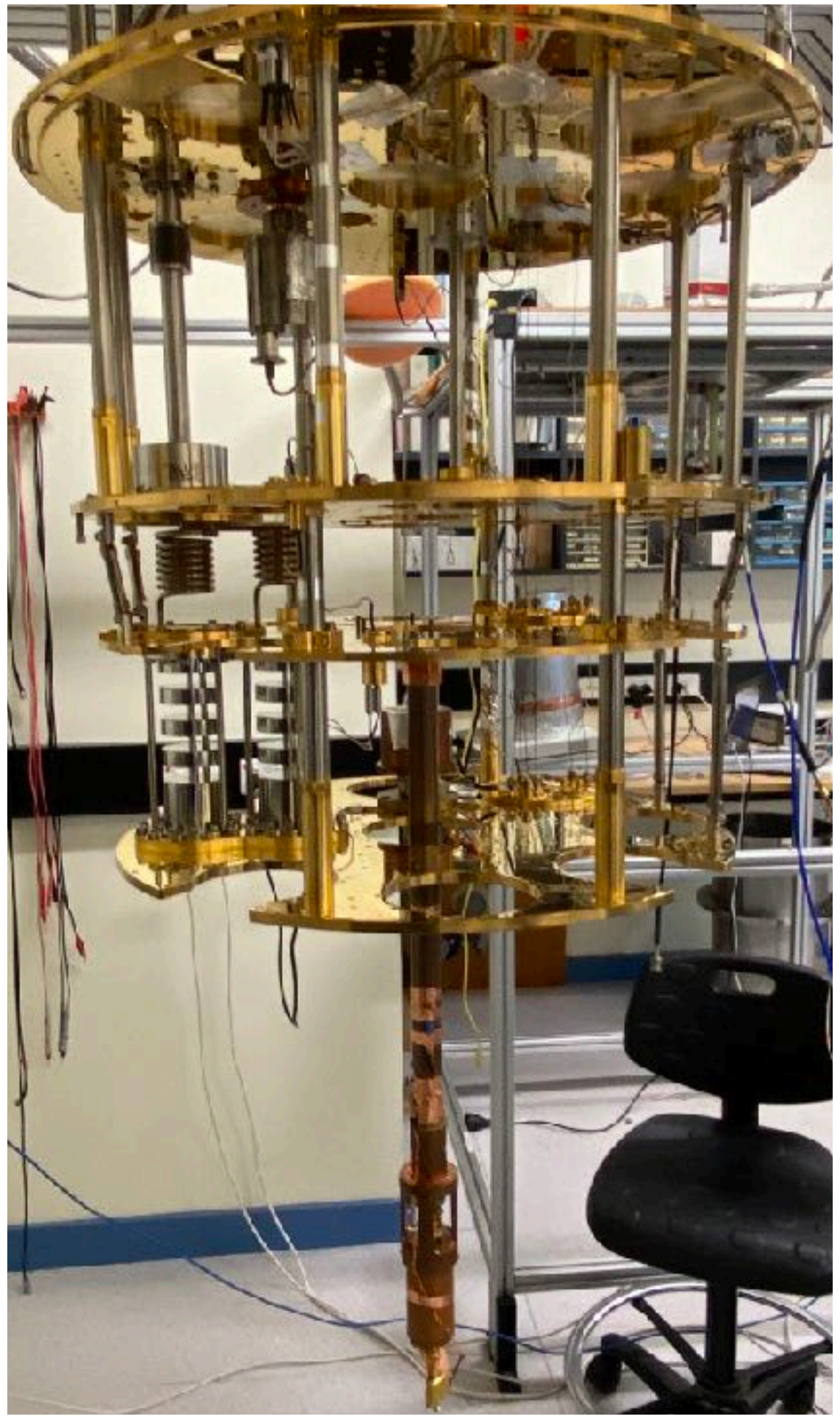
'Mode Map'



Phase 1a

- What do we mean by scanning?

Dilution fridge



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Step motor

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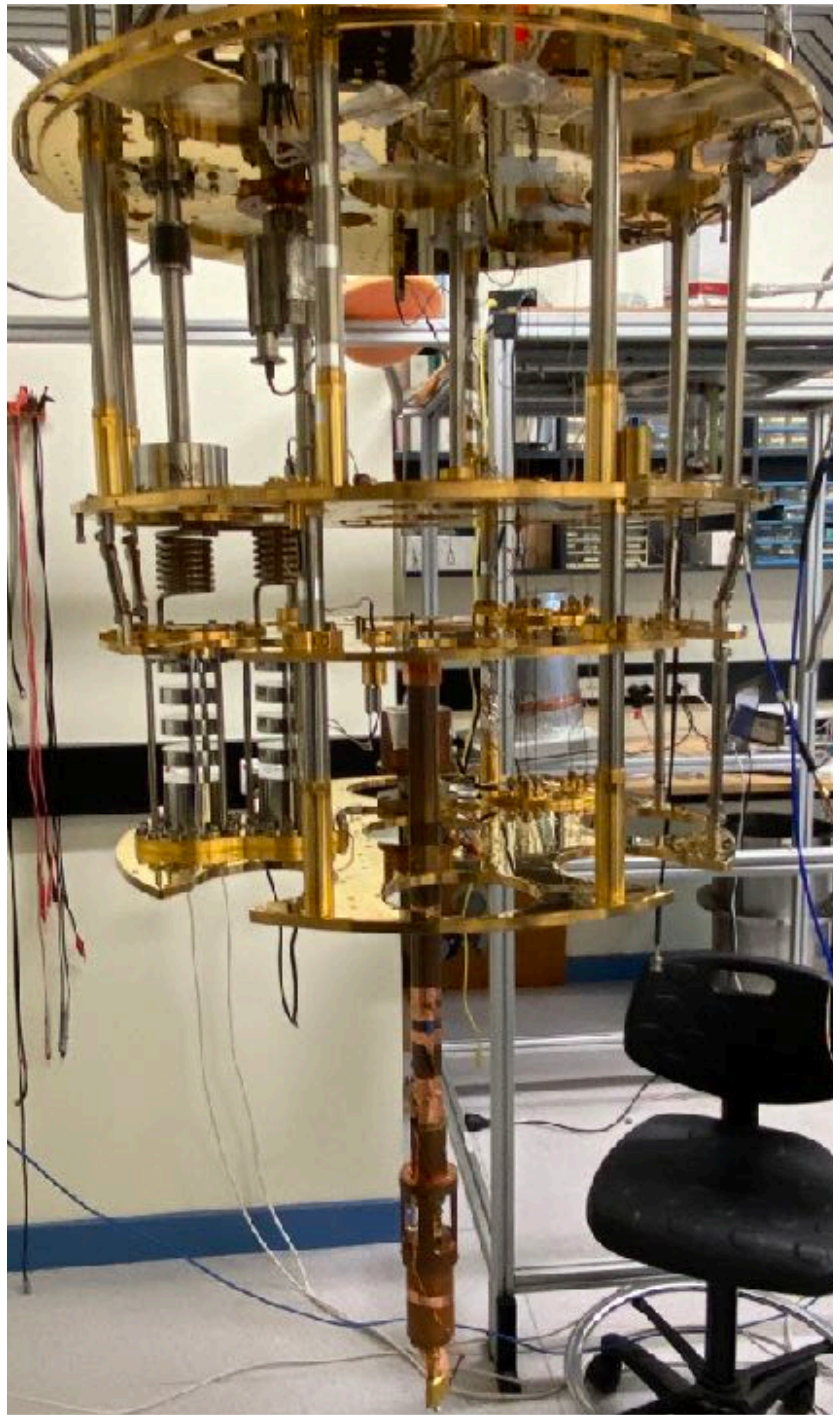

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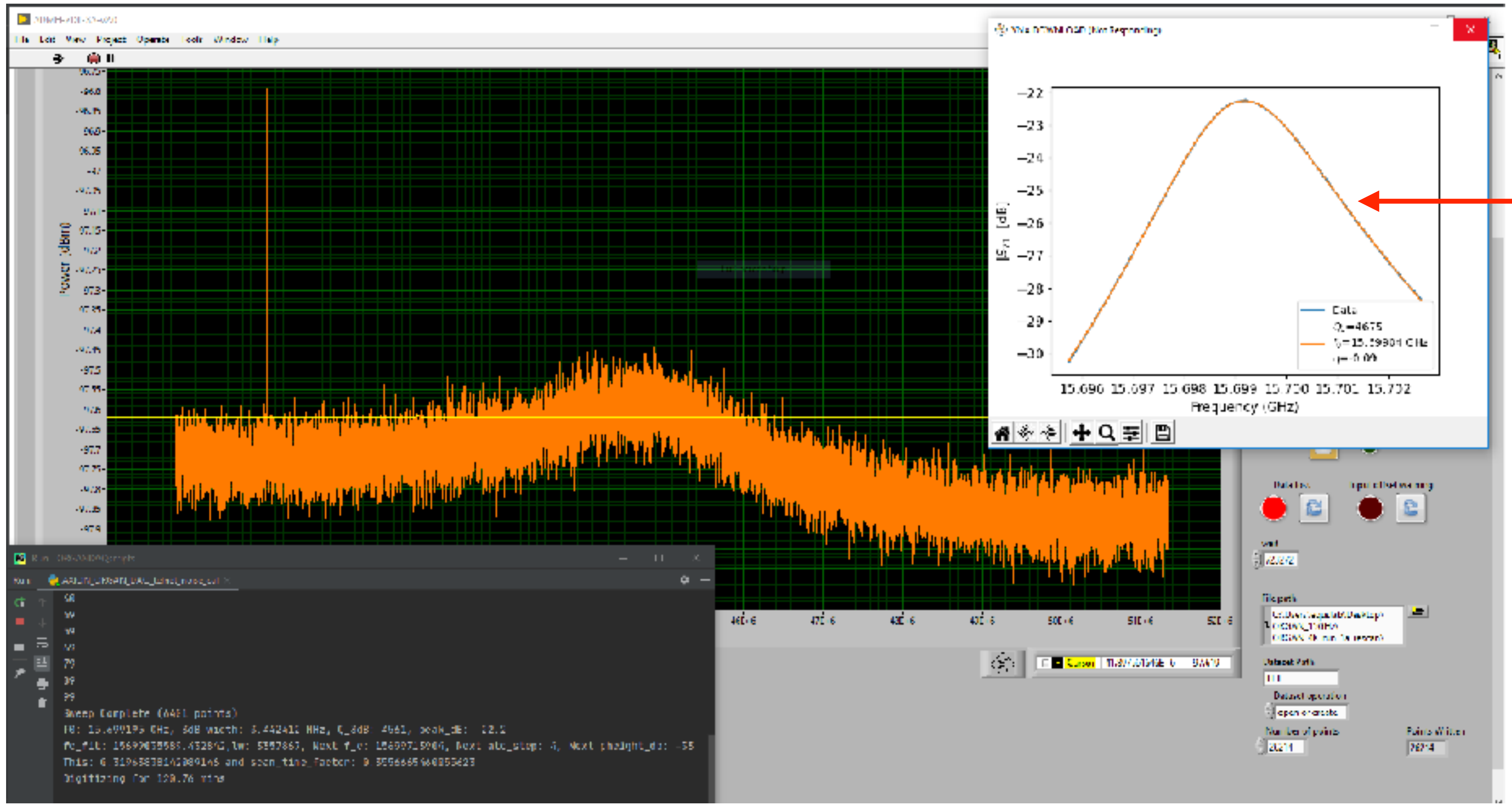
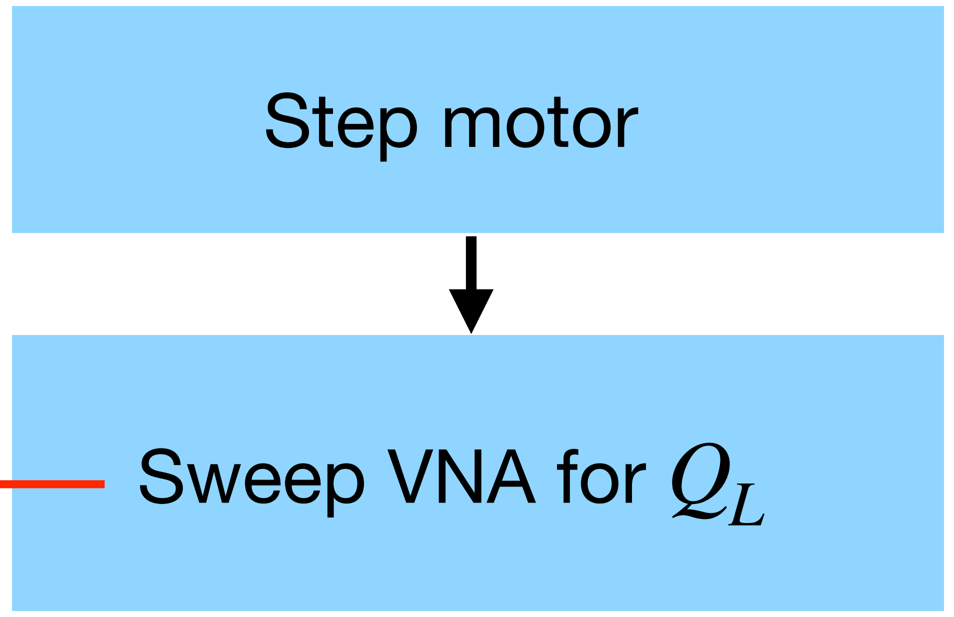


ORGAN DAQ



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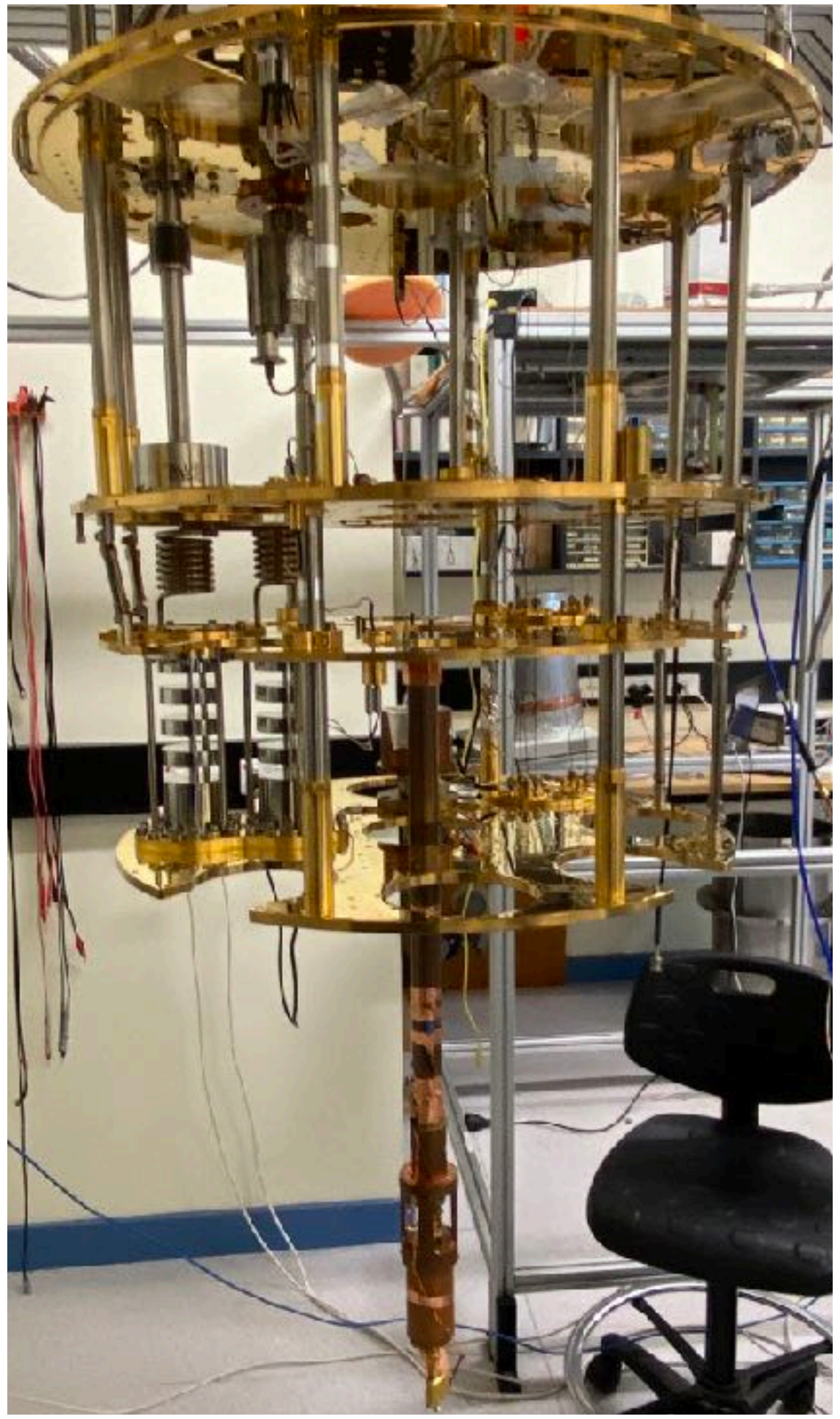

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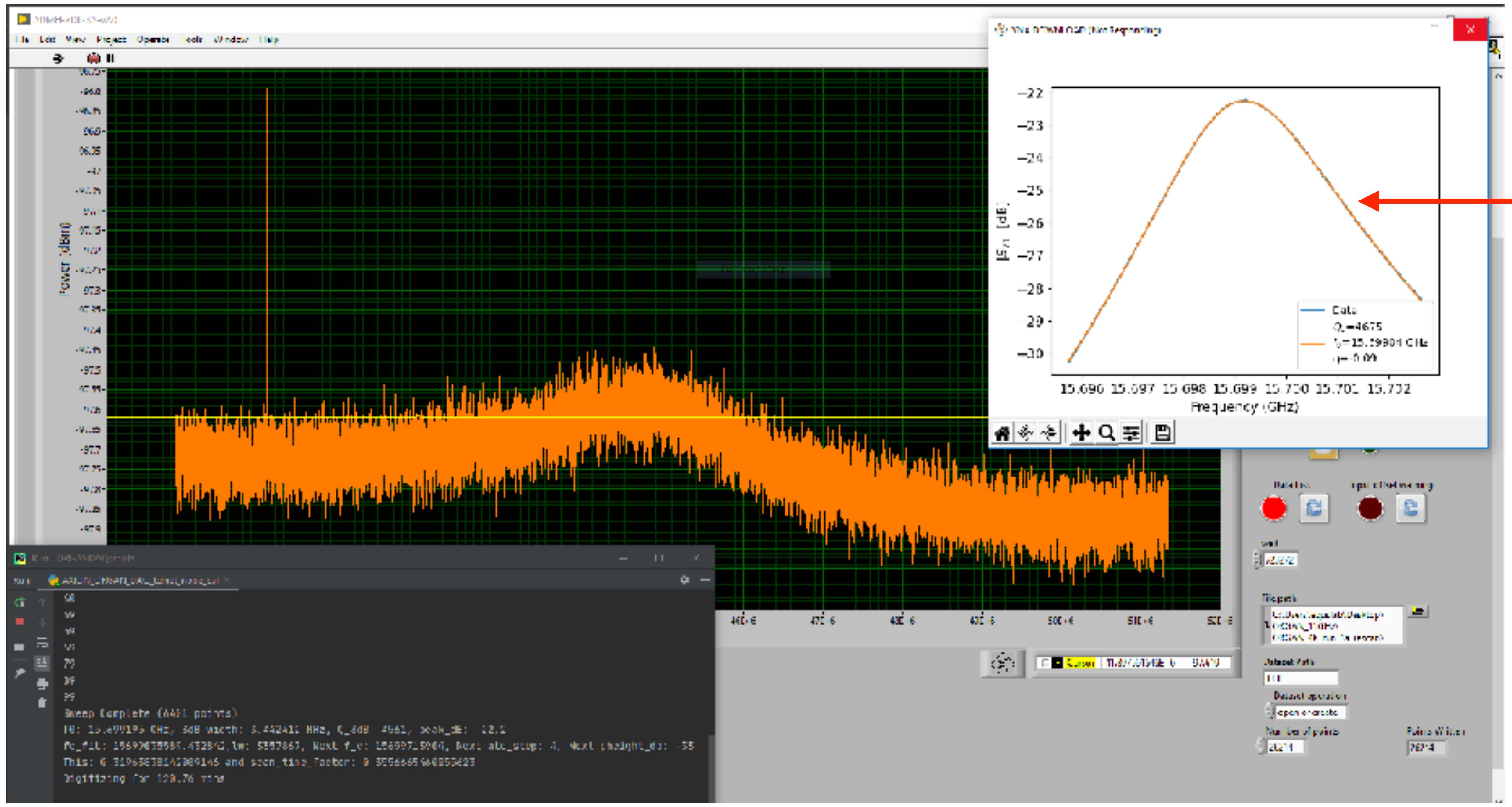

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Step motor

↓

Sweep VNA for Q_L

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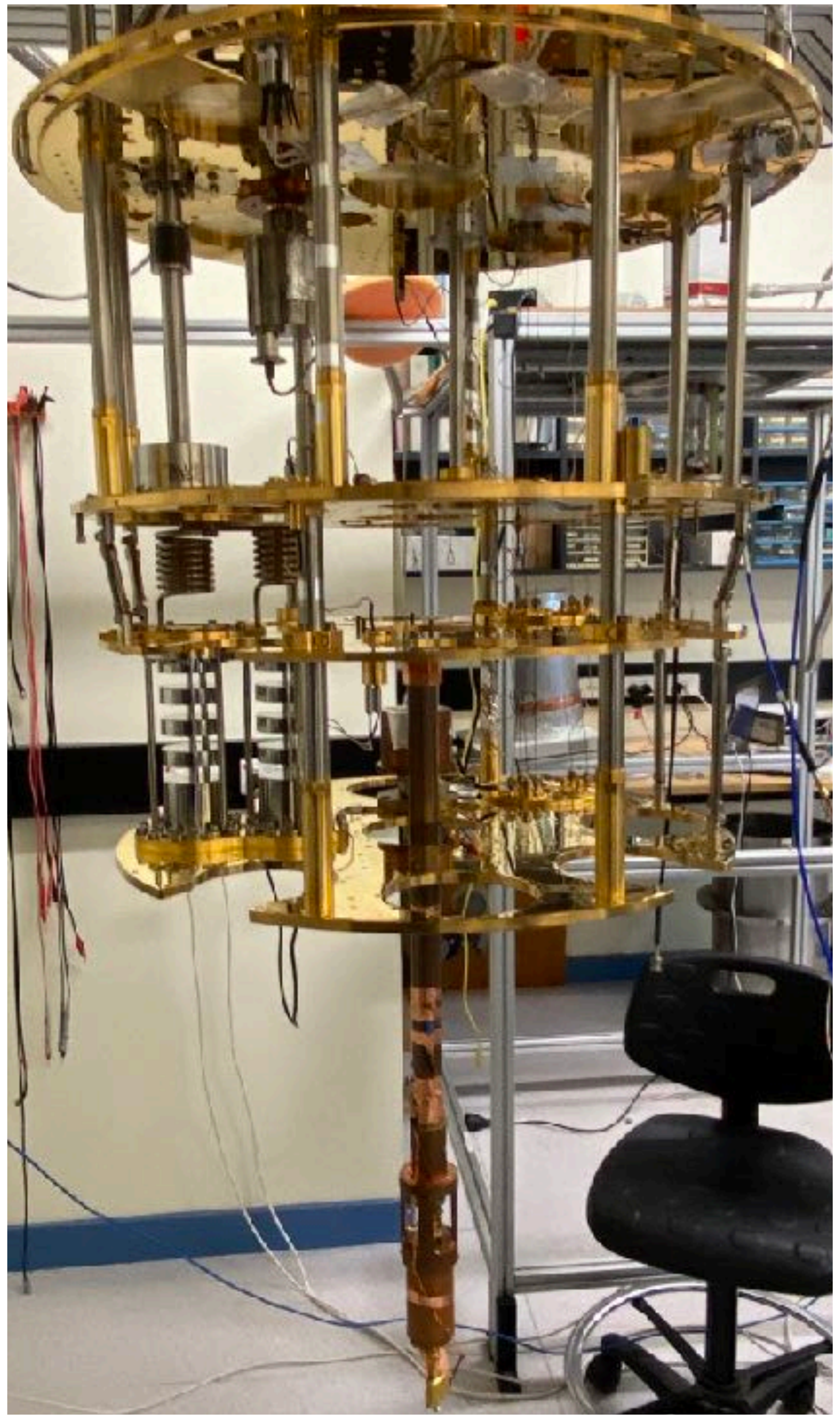

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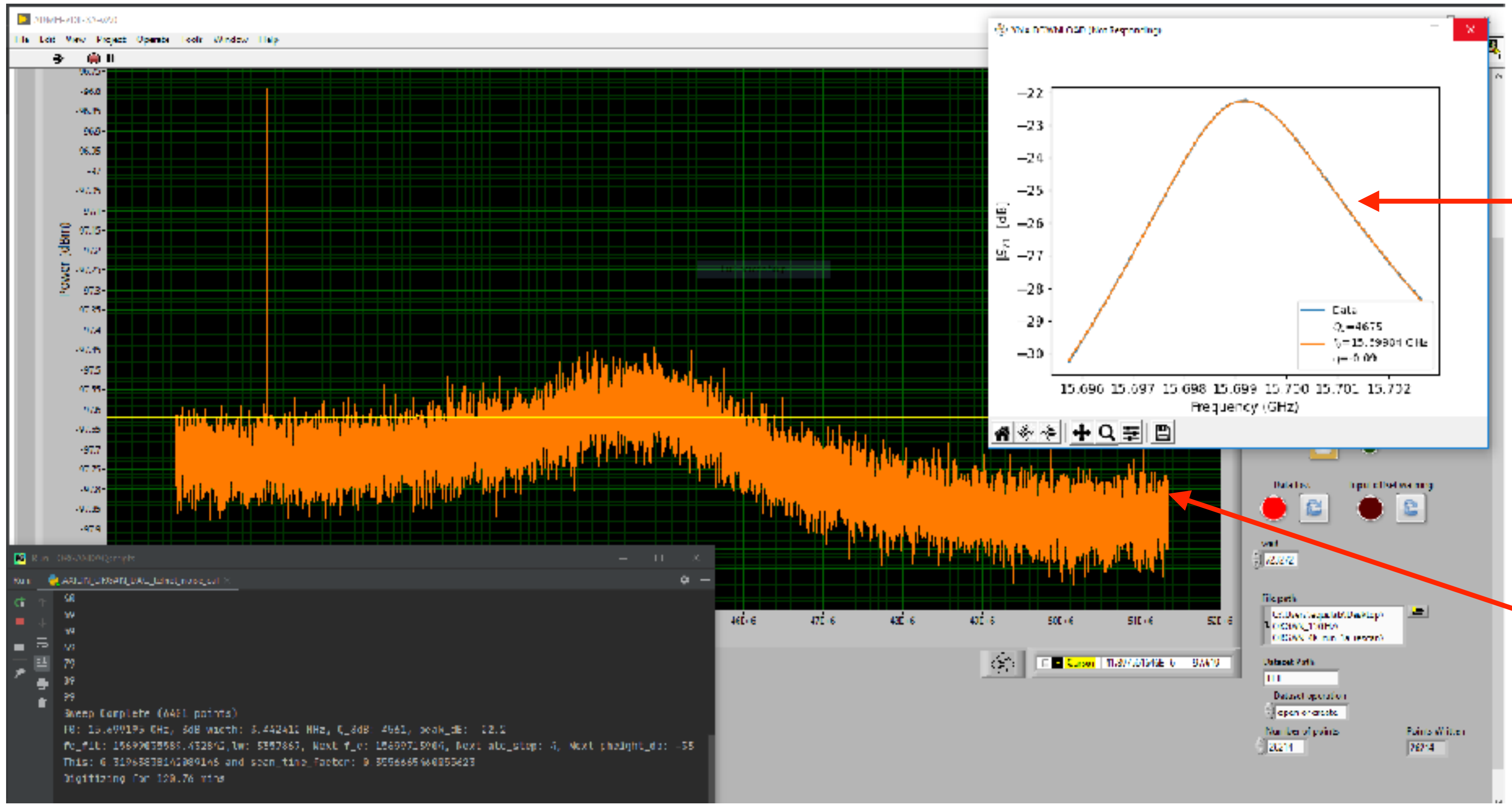

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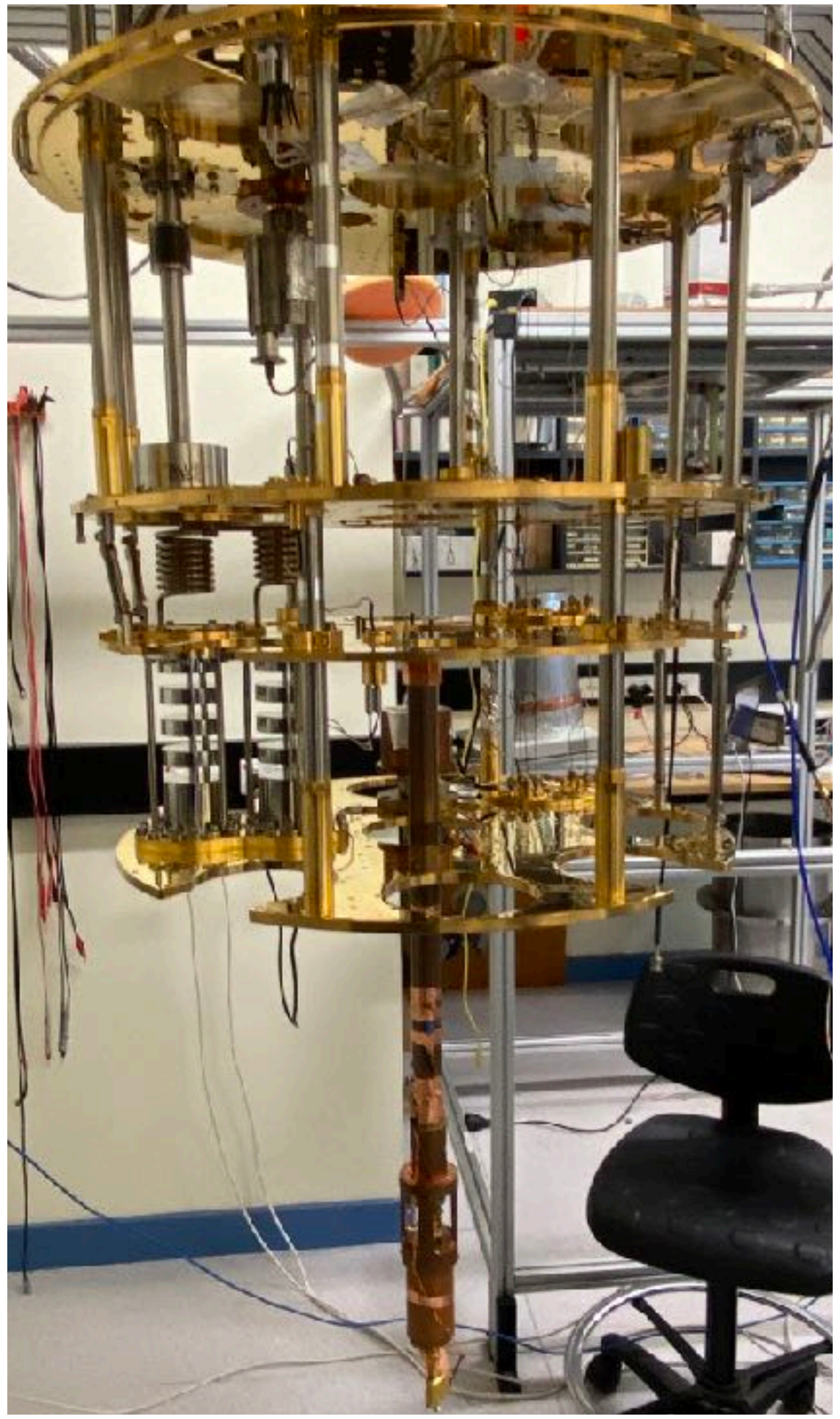
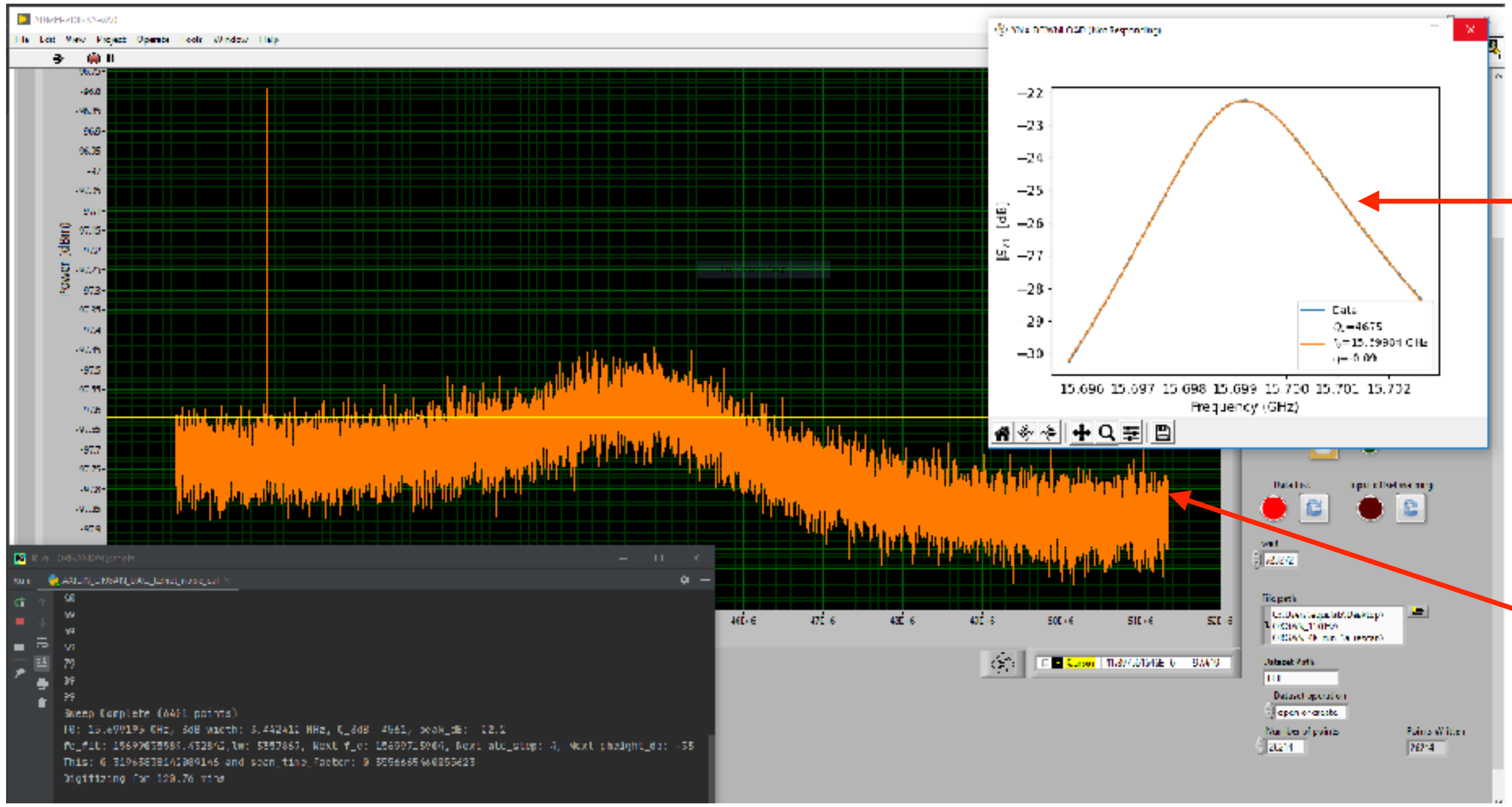
FFT

Dilution fridge

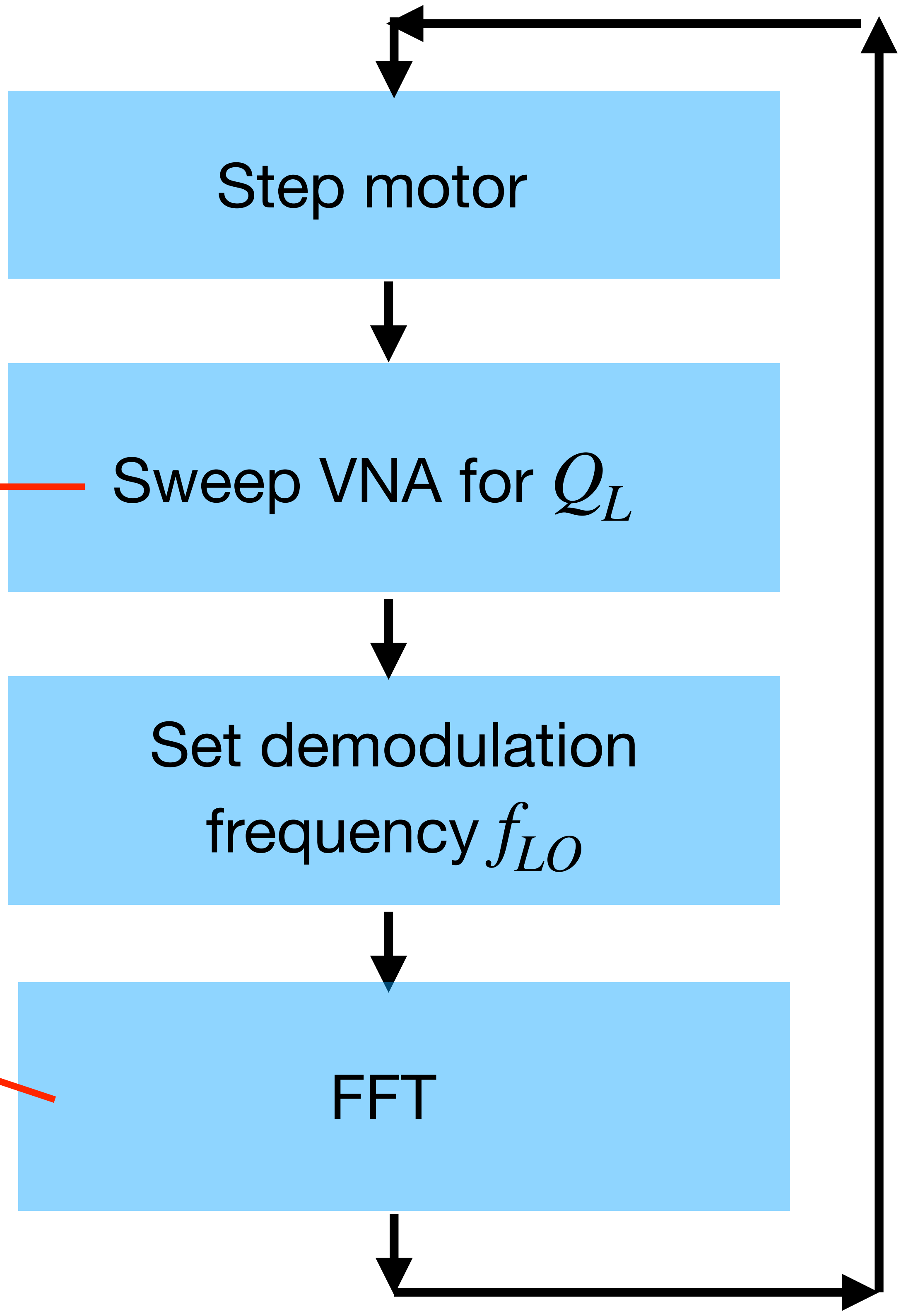


Phase 1a

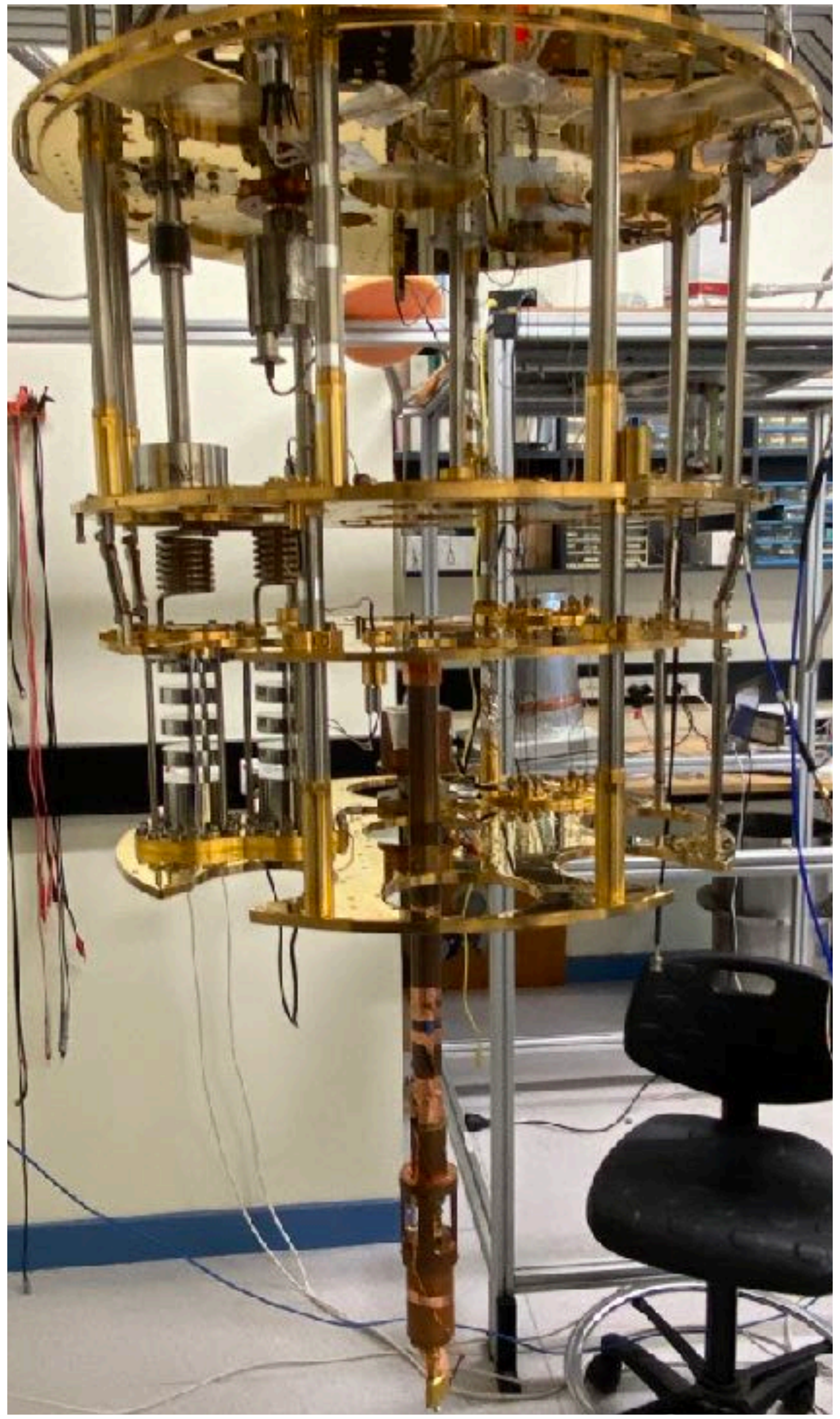
- What do we mean by scanning?



ORGAN DAQ



Dilution fridge



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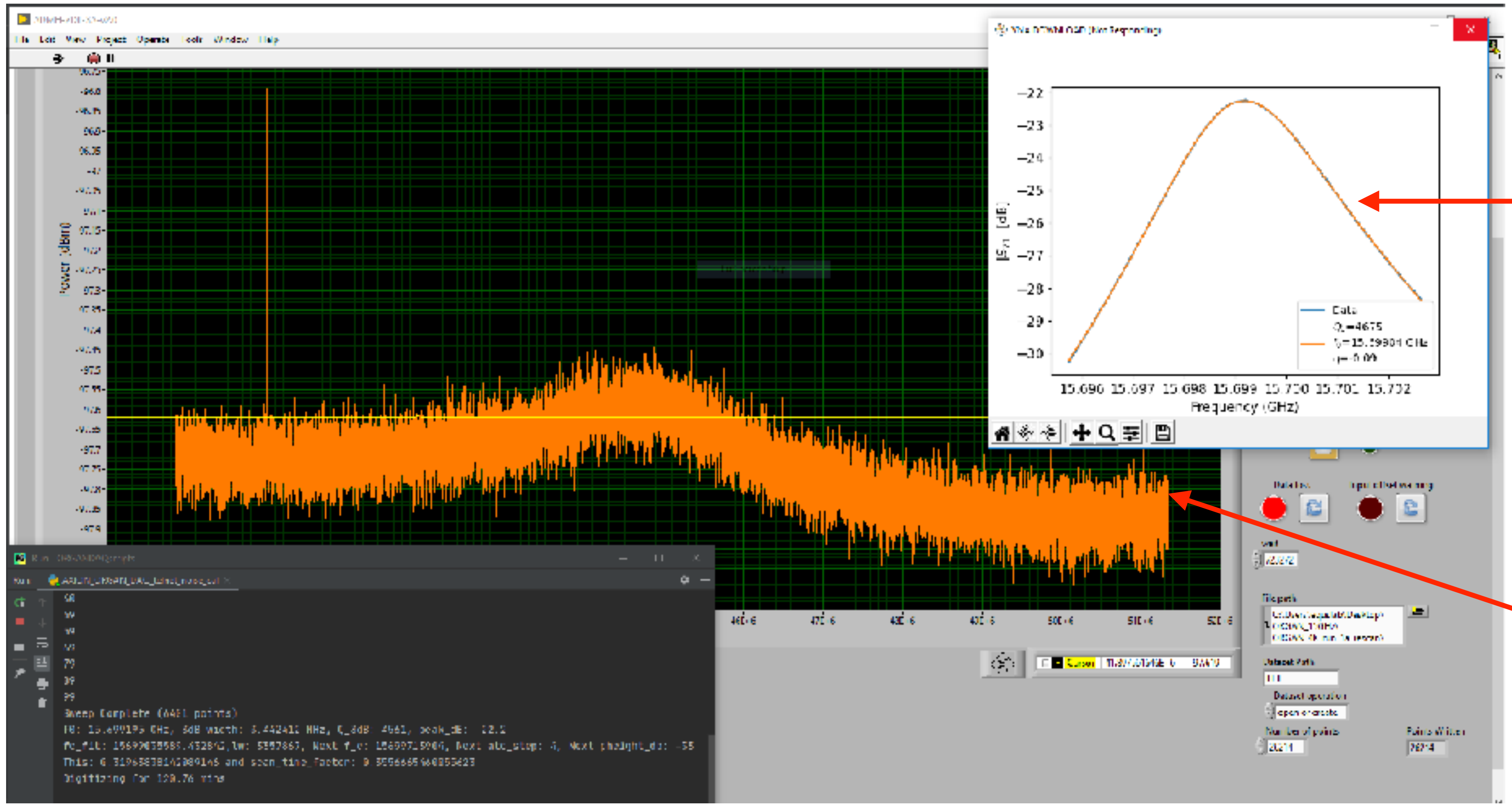
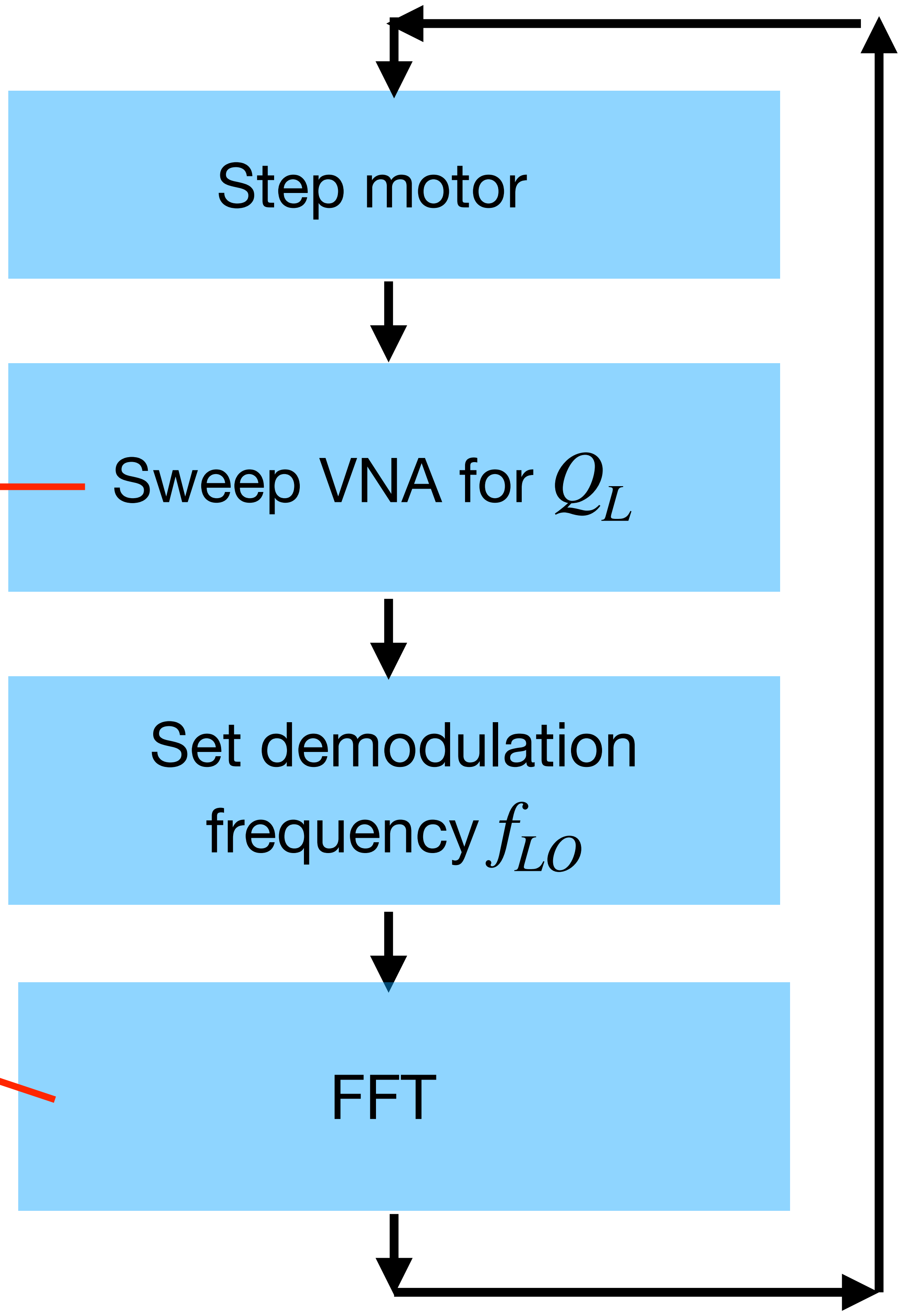


ORGAN DAQ



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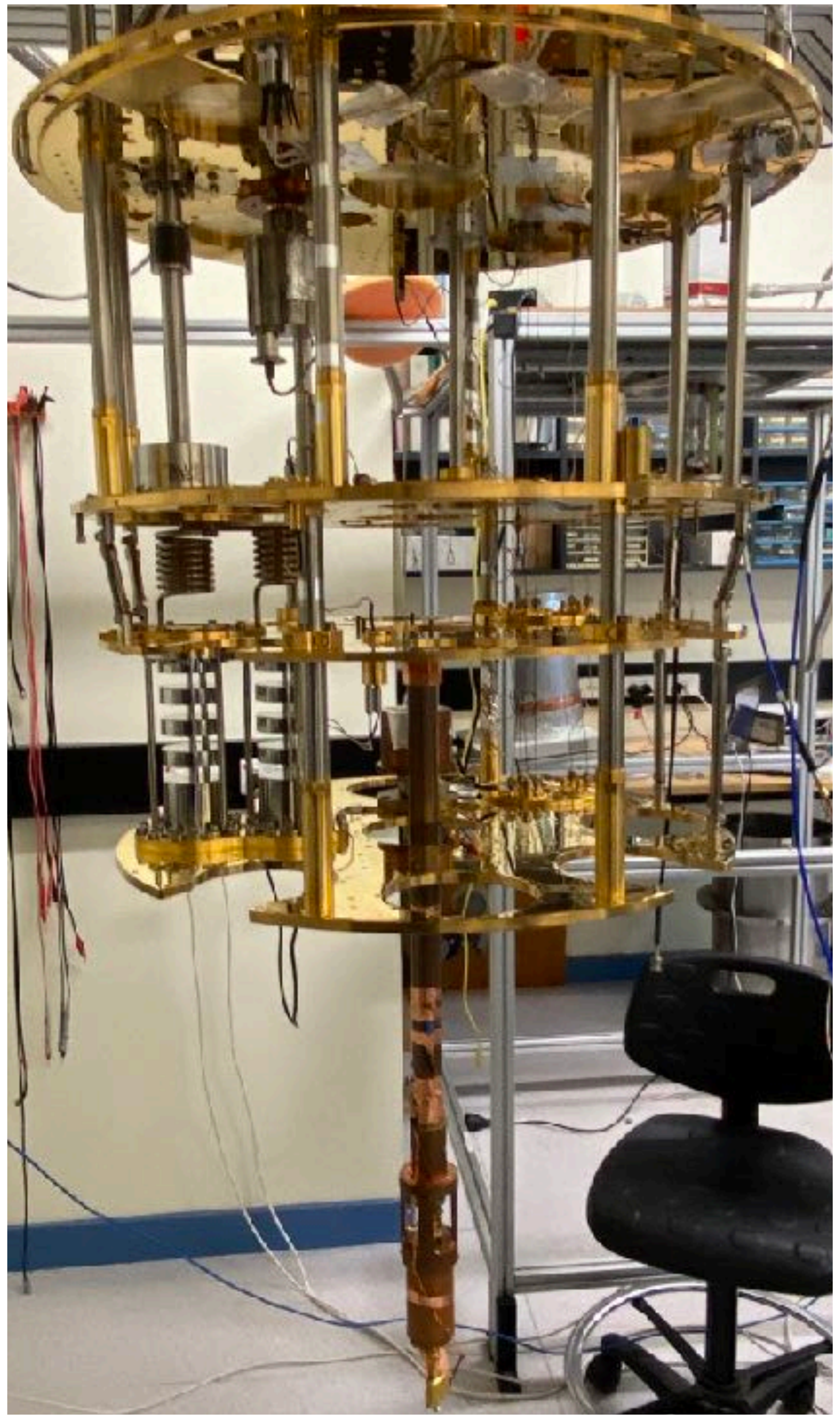

Look for axions!

Limits on other Dark Matter Candidates

Limits on other Dark Matter Candidates

- Placing limits ‘for free’ on other dark matter candidates

Limits on other Dark Matter Candidates

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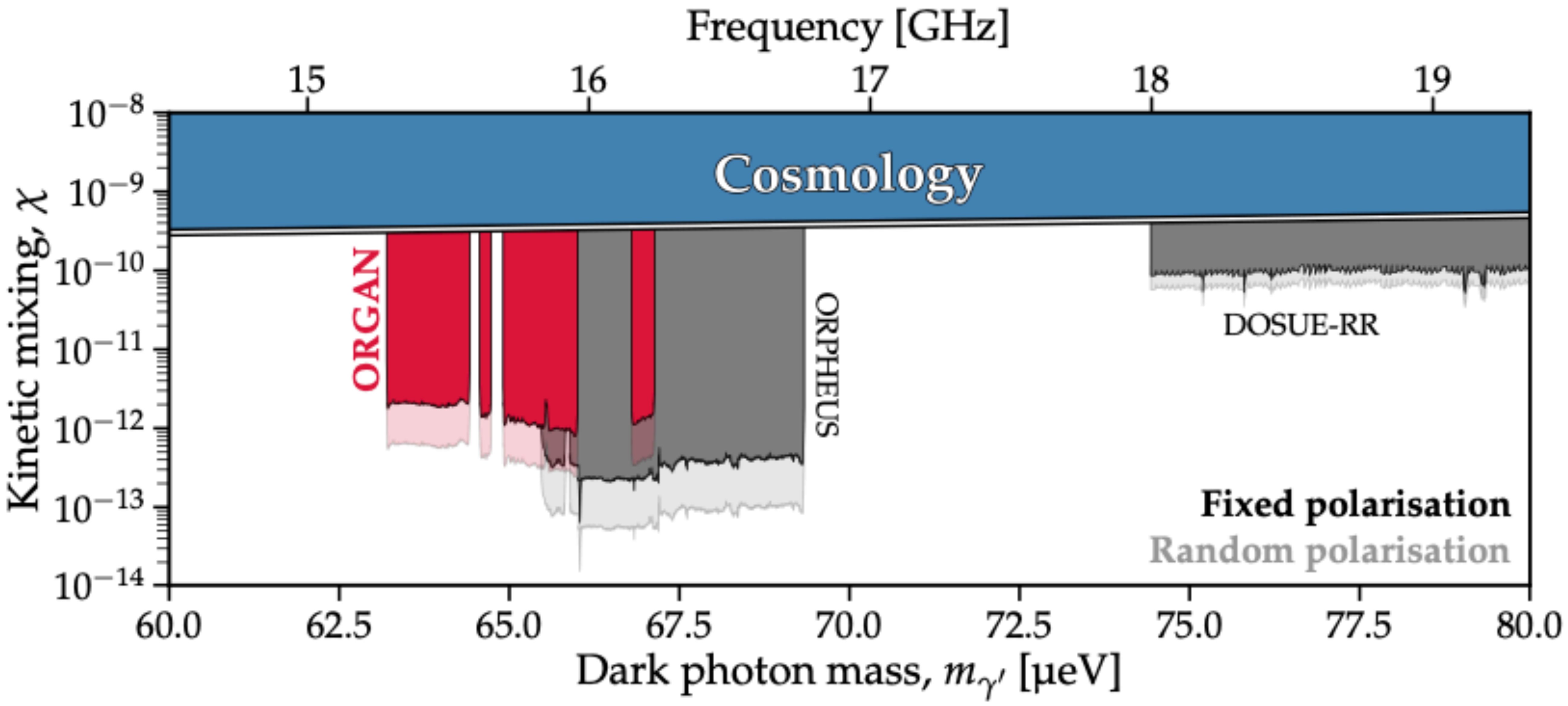
Limits on Dark Photons, Scalars, and Axion-Electromagnetodynamics with The ORGAN Experiment

Ben T. McAllister,[1,2,a] Aaron Quiskamp,[1,b] Ciaran A. J. O’Hare,[3]
Paul Altin,[4] Eugene N. Ivanov,[1] Maxim Goryachev,[1] and Michael E. Tobar[1,c]
[1] *QDM Laboratory, Department of Physics, University of Western Australia, 35 Stirling Highway, Crawley WA 6009, Australia.*
[2] *Centre for Astrophysics and Supercomputing, Swinburne University of Technology, John St, Hawthorn VIC 3122, Australia*
[3] *School of Physics, Physics Road, The University of Sydney, NSW 2006 Camperdown, Sydney, Australia*
[4] *ARC Centre of Excellence For Engineered Quantum Systems, The Australian National University, Canberra ACT 2600 Australia*
(Dated: December 6, 2022)



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- Placing limits ‘for free’ on other dark matter candidates
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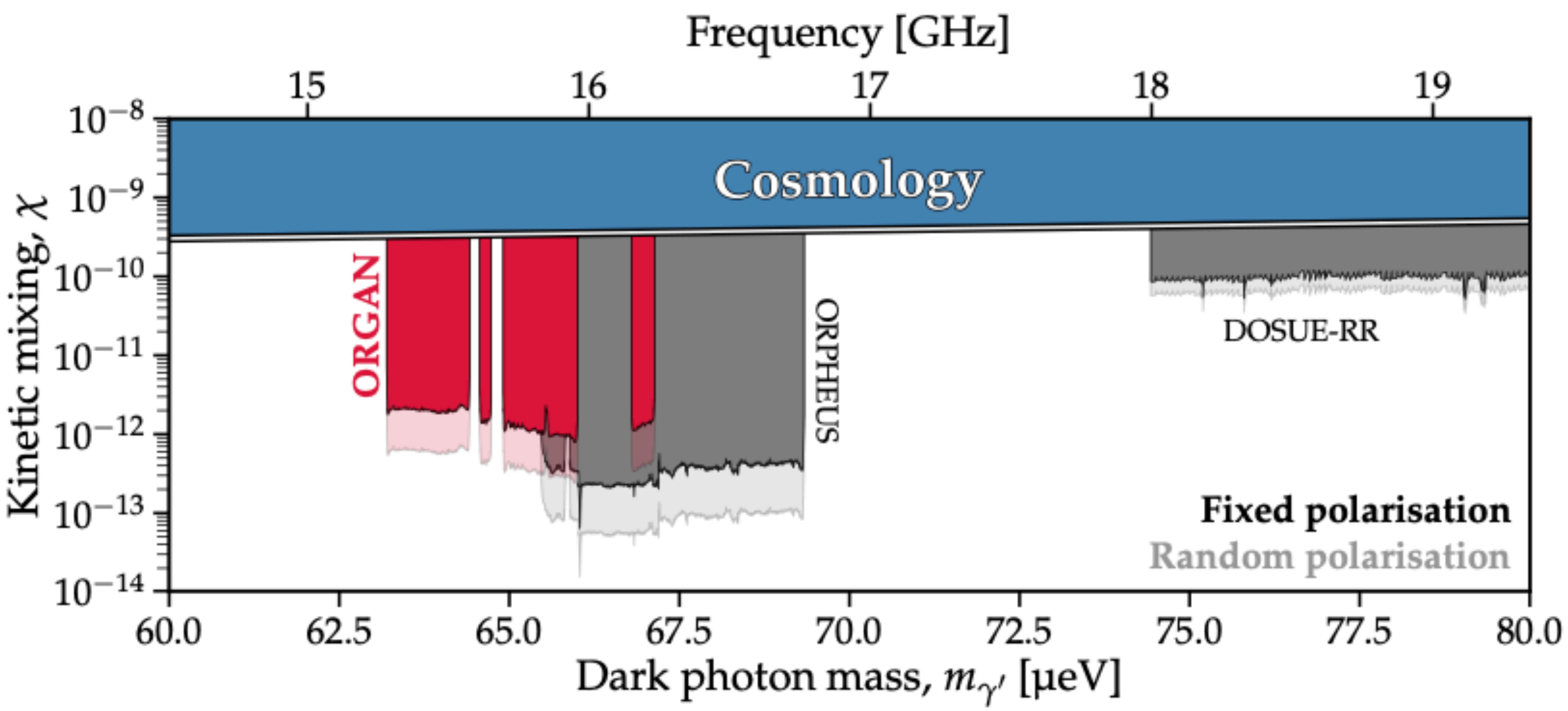

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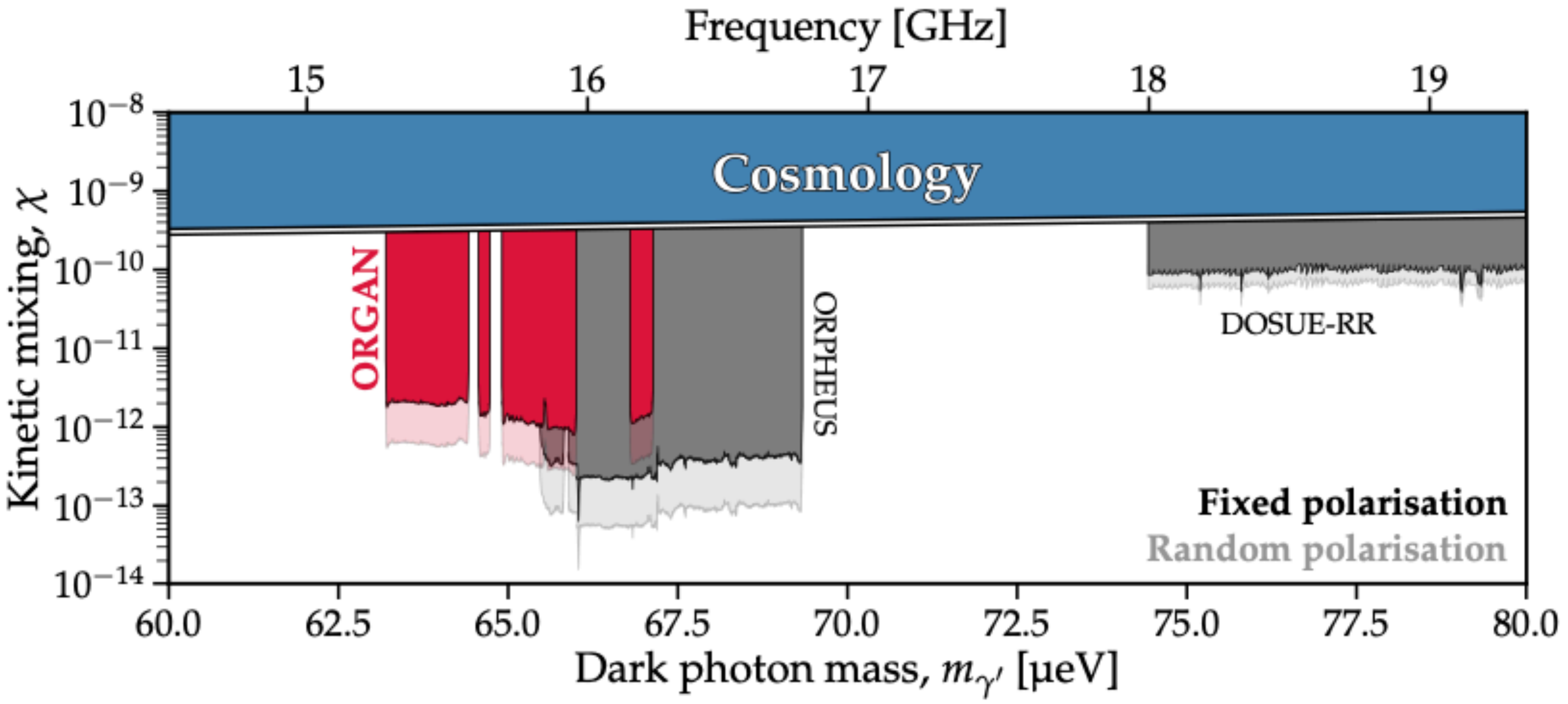

Limits on other Dark Matter Candidates

- Placing limits ‘for free’ on other dark matter candidates
- Dark photons convert to detectable photons
- Simple scaling of Axion limits to Dark Photon limits
- Scalar dark matter (eg. dilaton) limits can also be placed

Limits on Dark Photons, Scalars, and Axion-Electromagnetodynamics with The ORGAN Experiment

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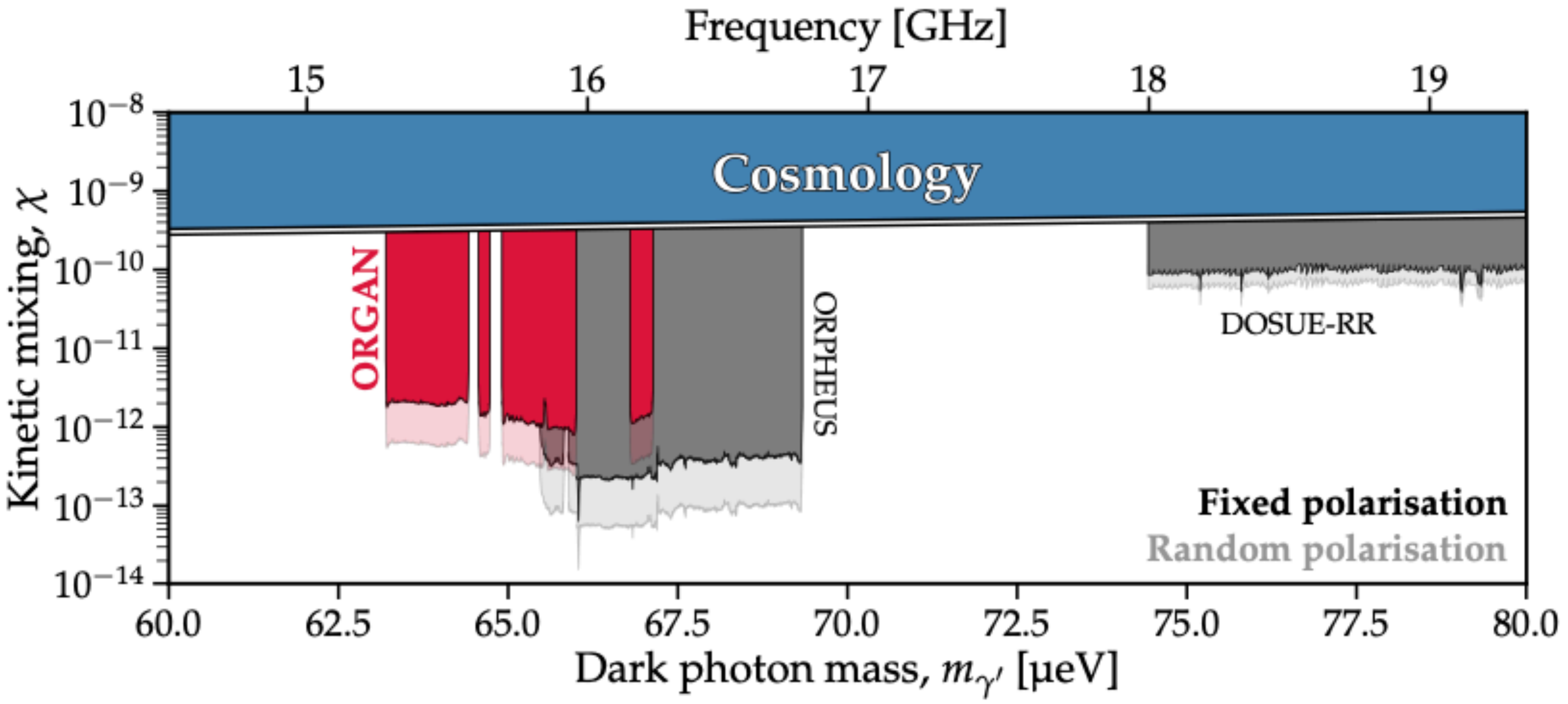


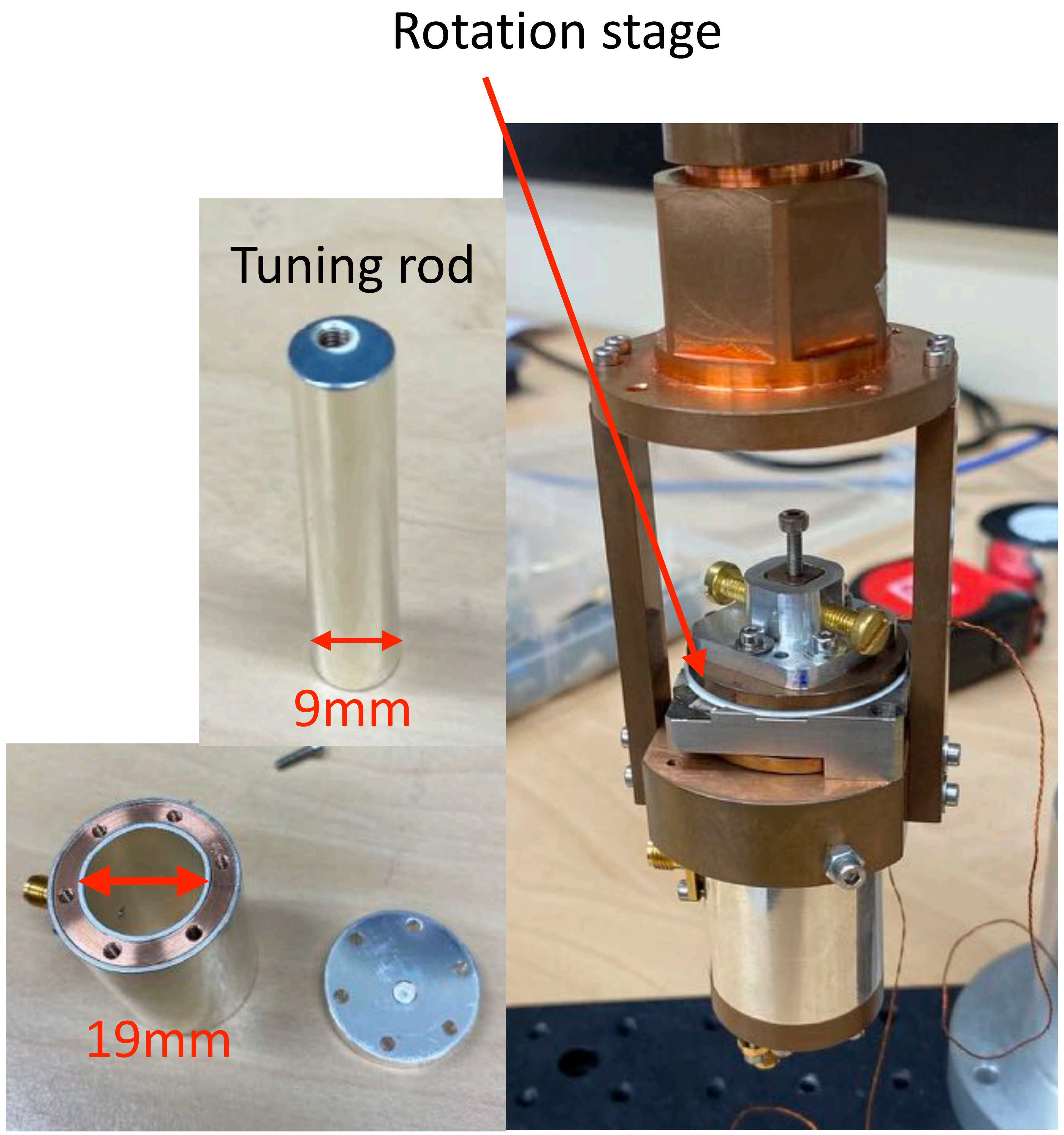
Phase 1b

Phase 1b

- Search between ~26-27 GHz

Phase 1b

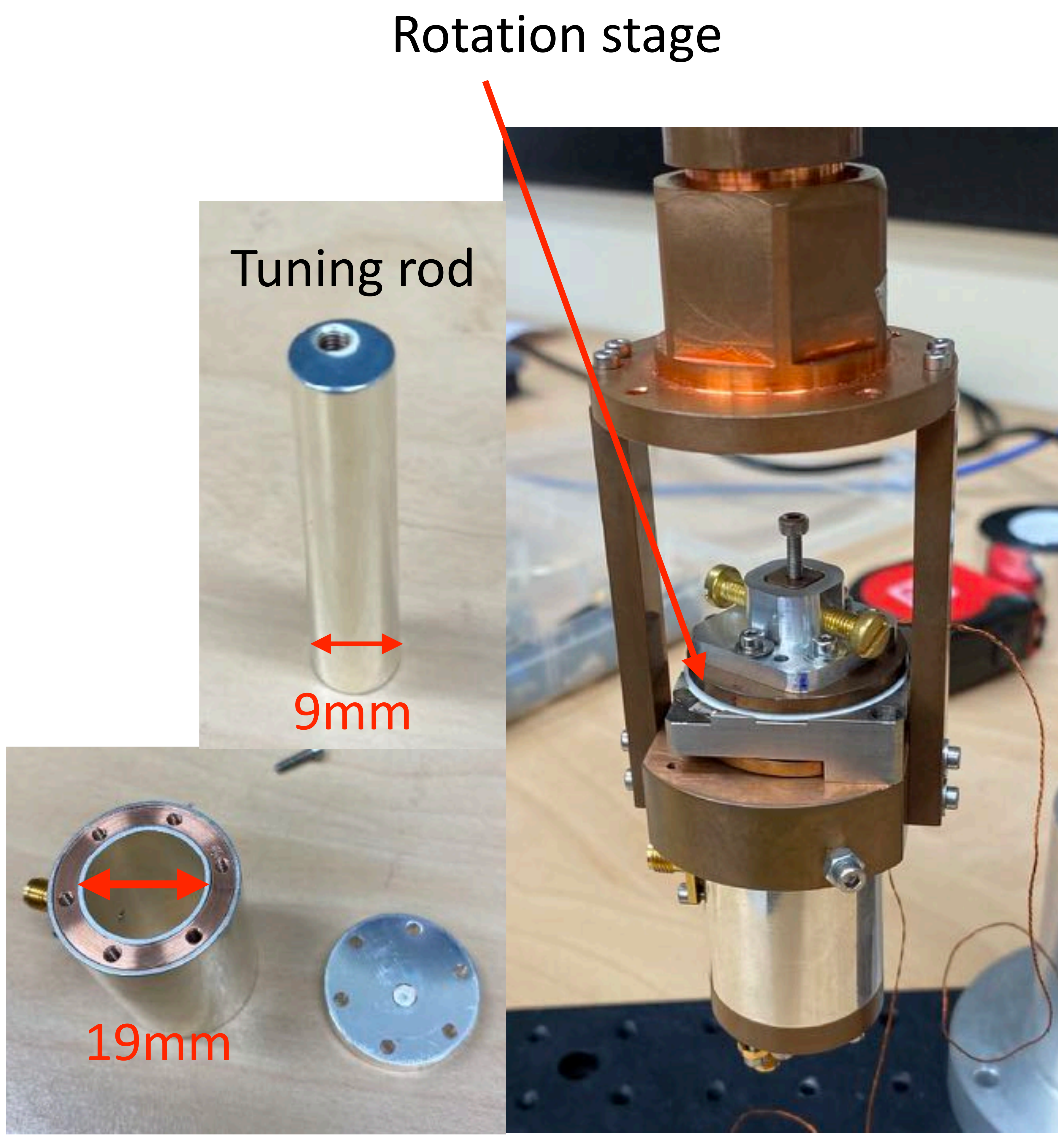
- Search between ~26-27 GHz
- Length scale ~45% smaller than phase 1a



26GHz tuning-rod cavity

Phase 1b

- Search between ~26-27 GHz
- Length scale ~45% smaller than phase 1a
- High frequency is difficult —> Resonator is **<u>necessarily</u>** small
- Relative tolerances are much bigger



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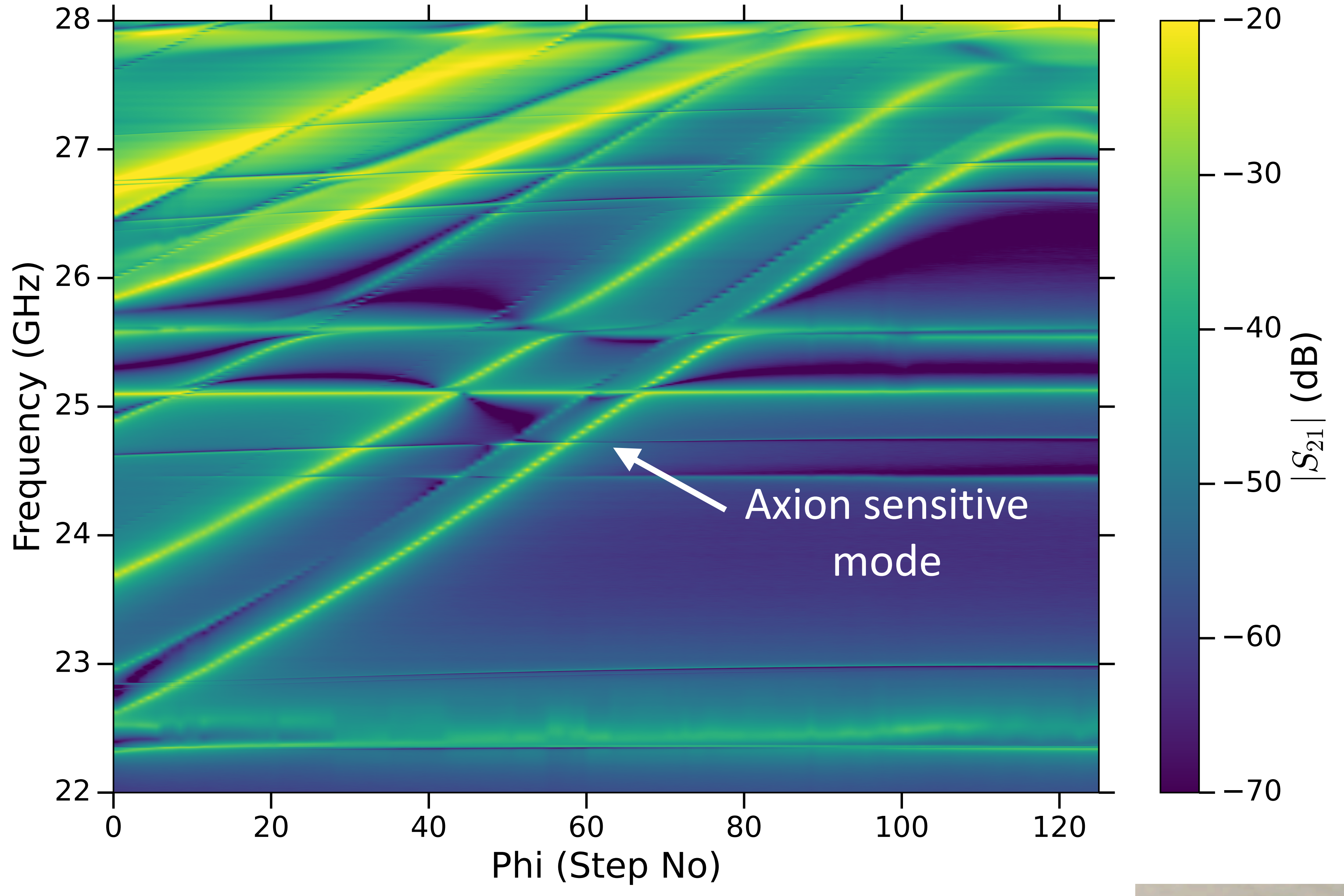

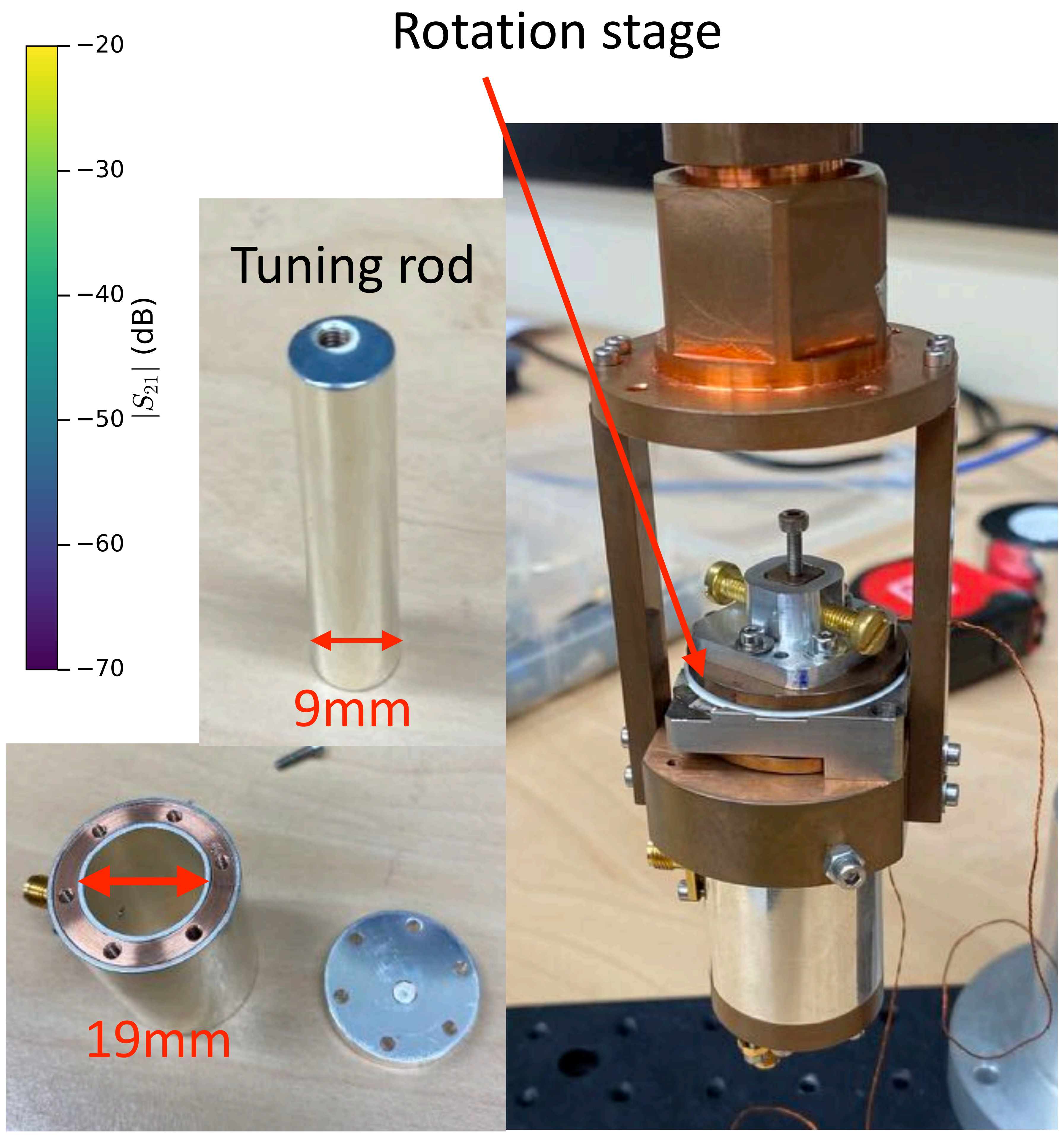

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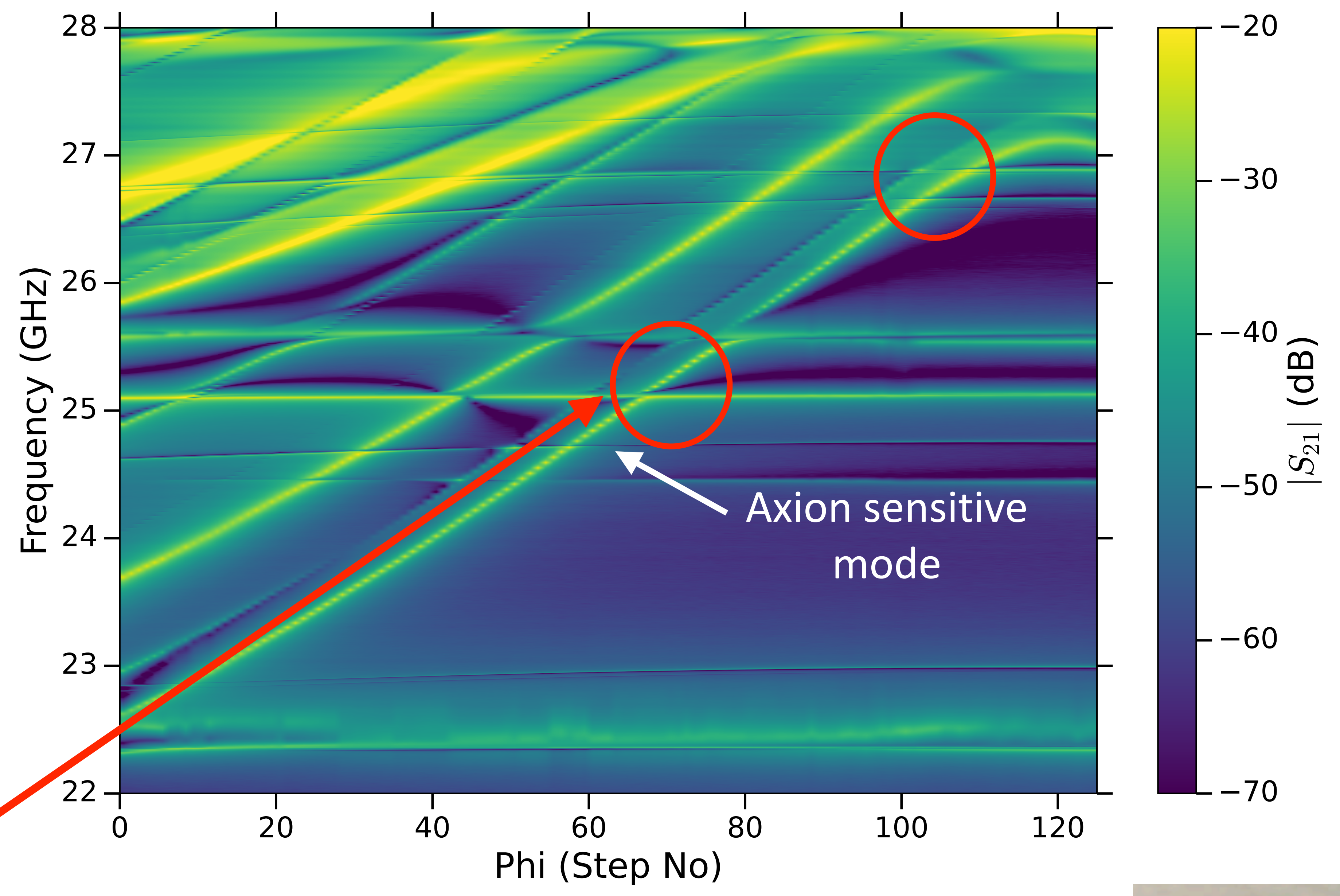

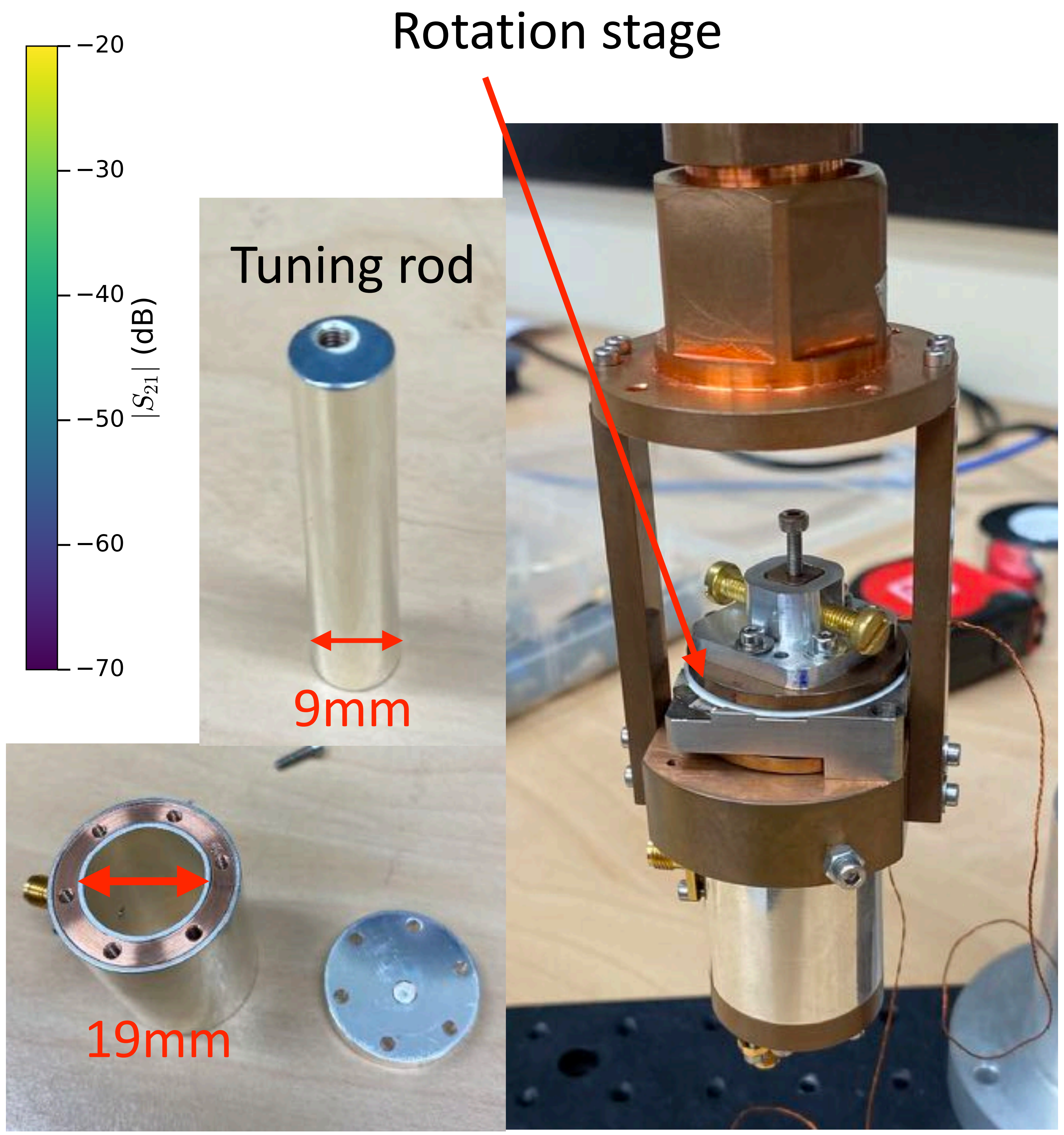

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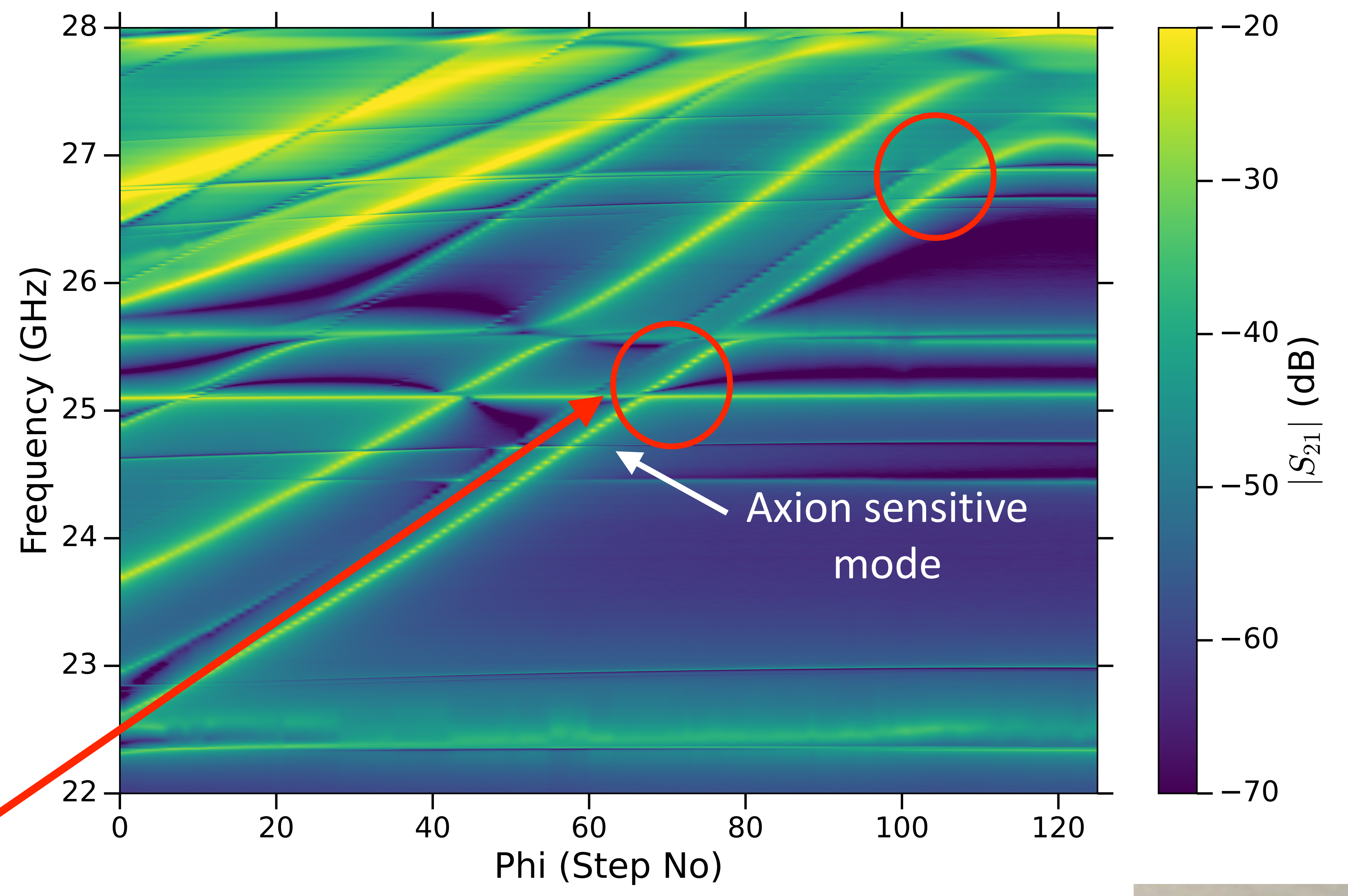
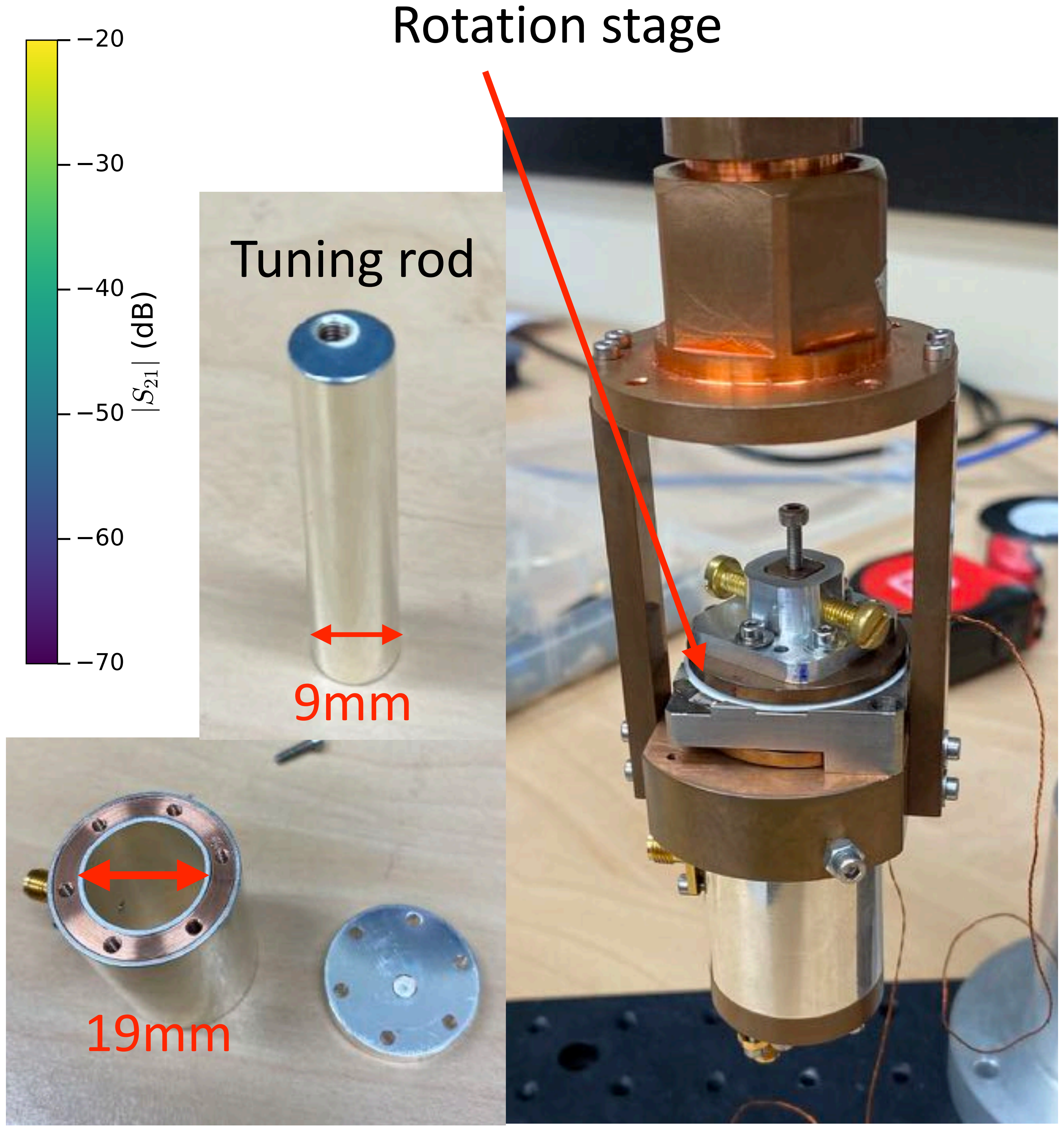
- Extremely sensitive to alignment and rod tilt





26GHz tuning-rod cavity

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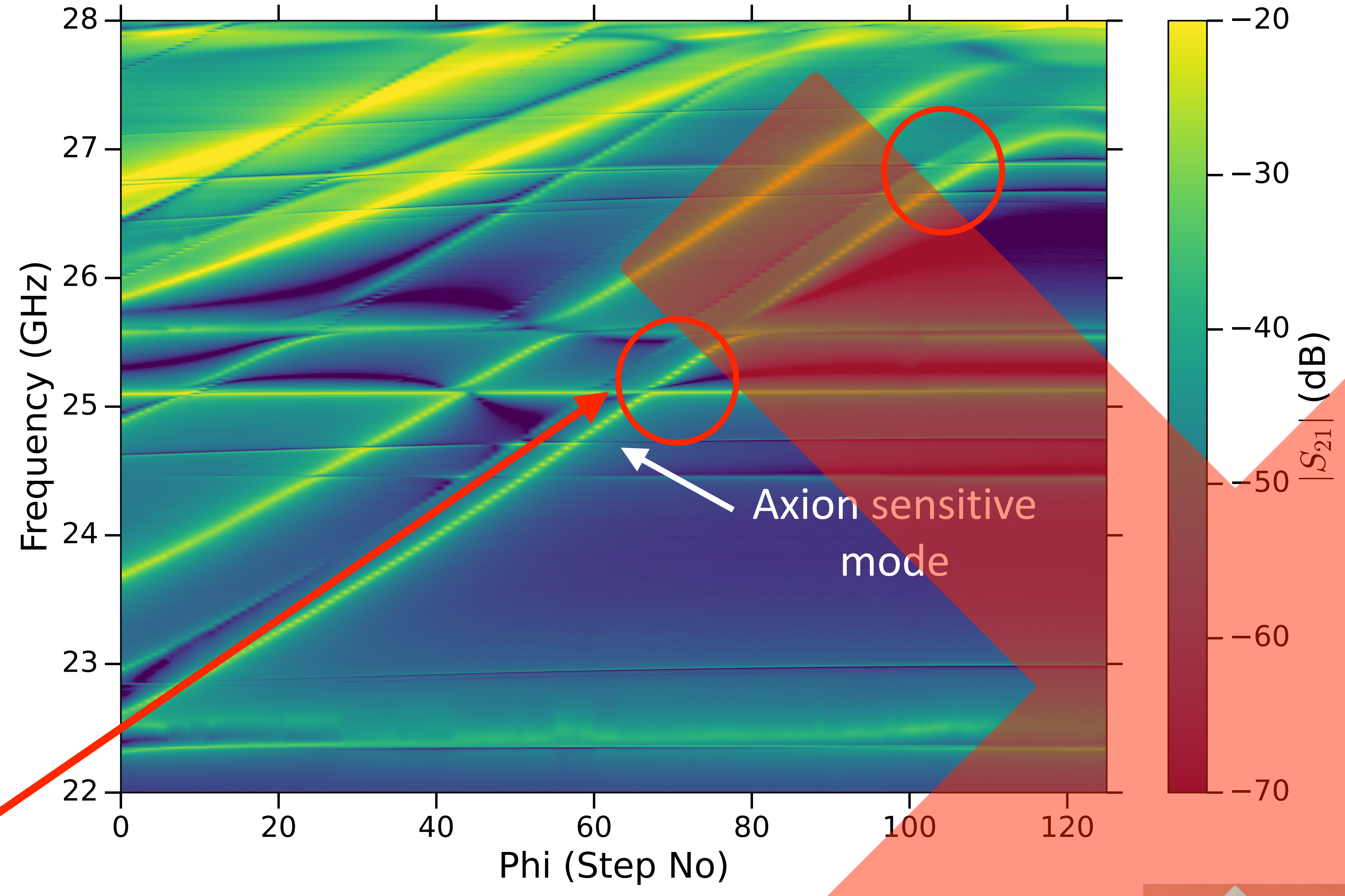
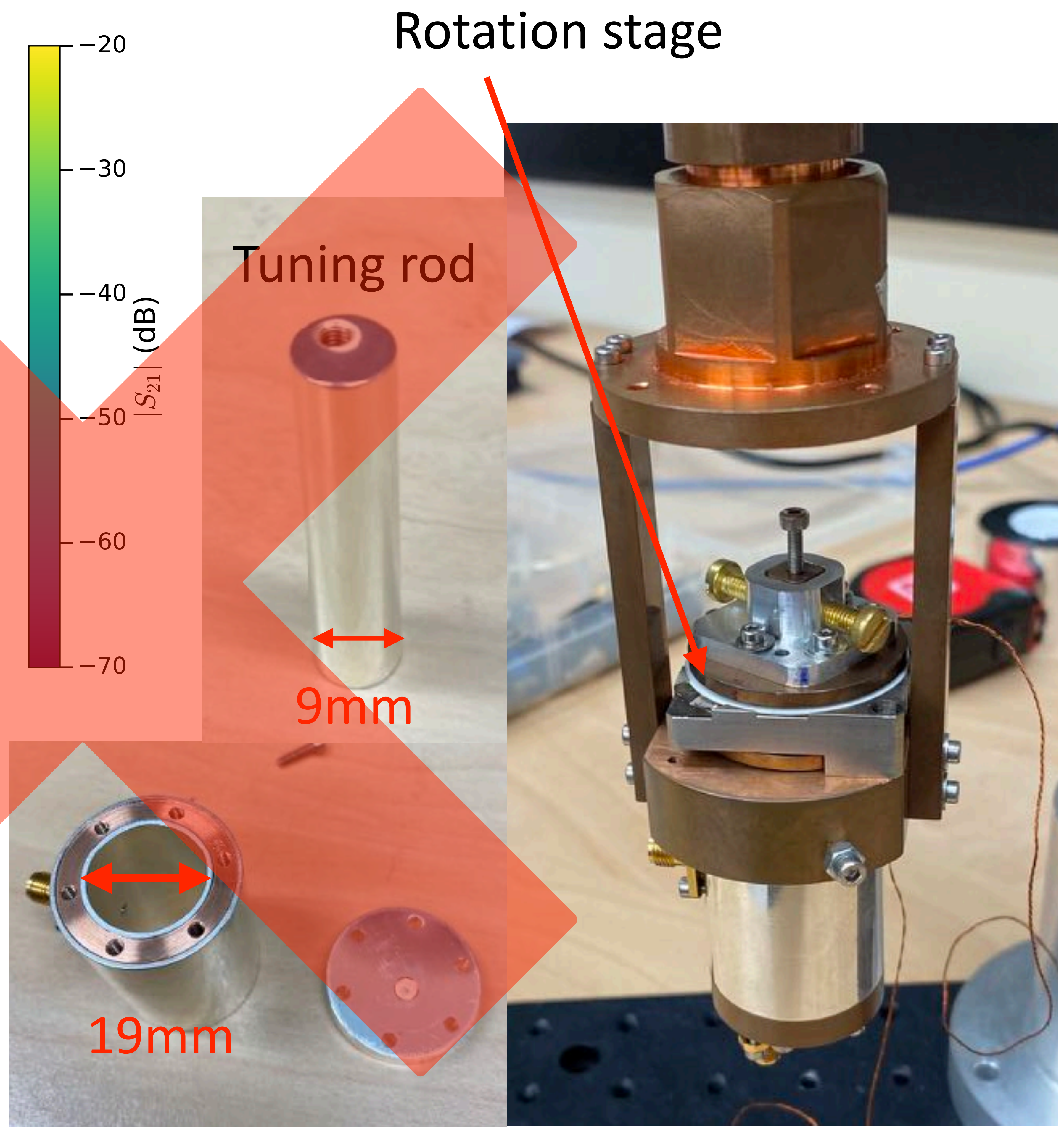
- High frequency is difficult —> Resonator is **necessarily** small
- Relative tolerances are much bigger
- Greater number of mode crossings
- Extremely sensitive to alignment and rod tilt
- **Novel high frequency resonator designs are needed!**





26GHz tuning-rod cavity

Phase 1b

Phase 1b

- Simple idea by Ben McAllister

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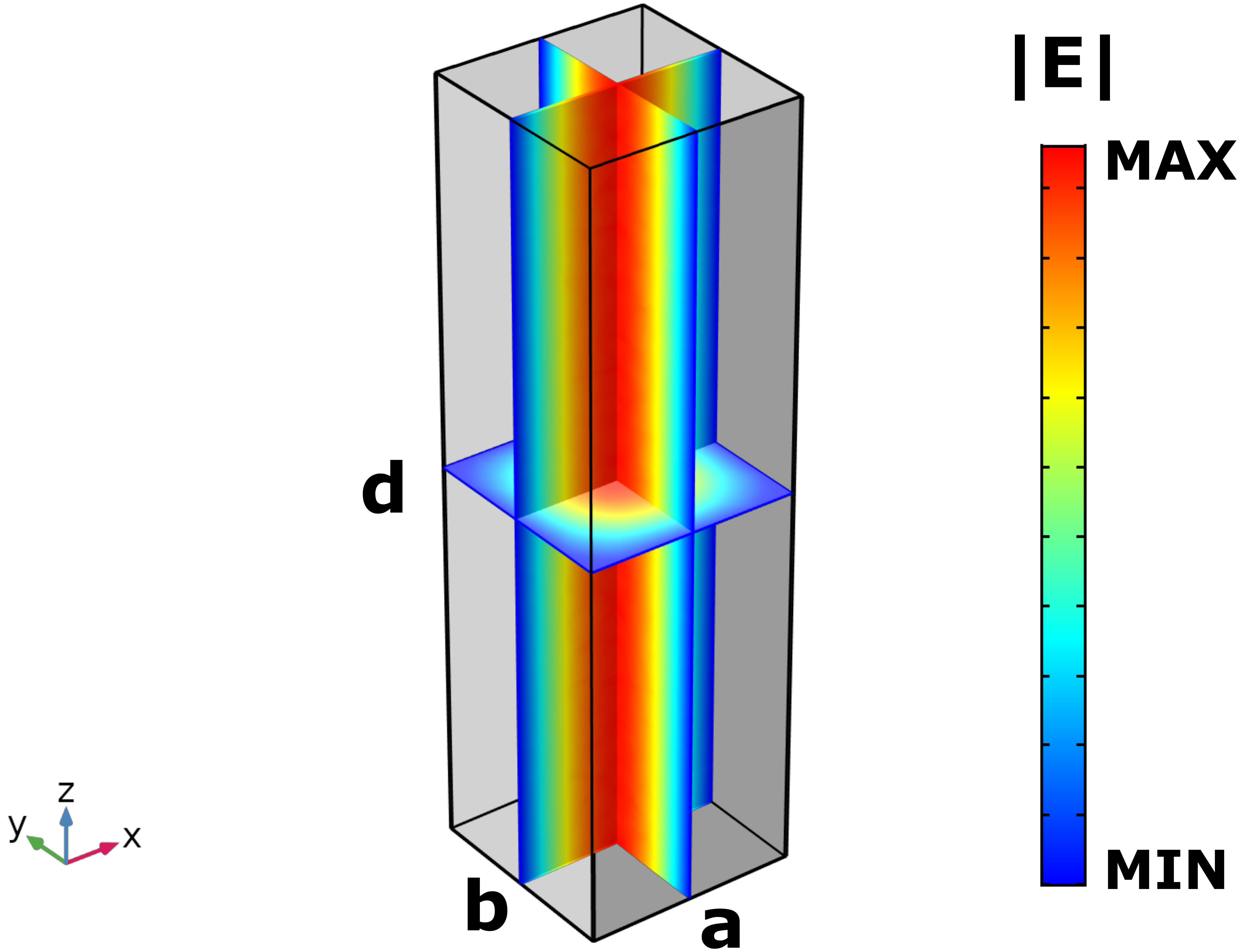

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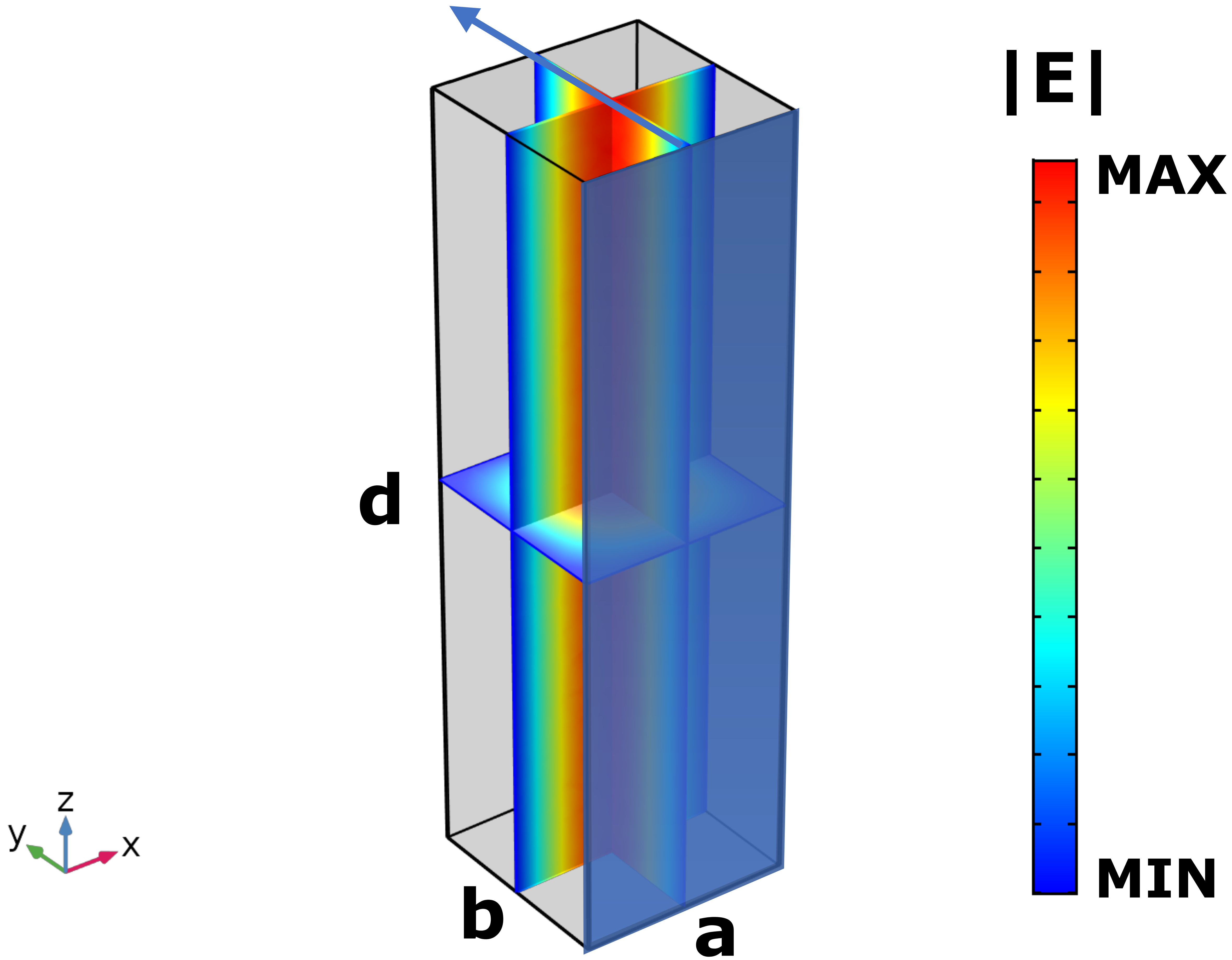

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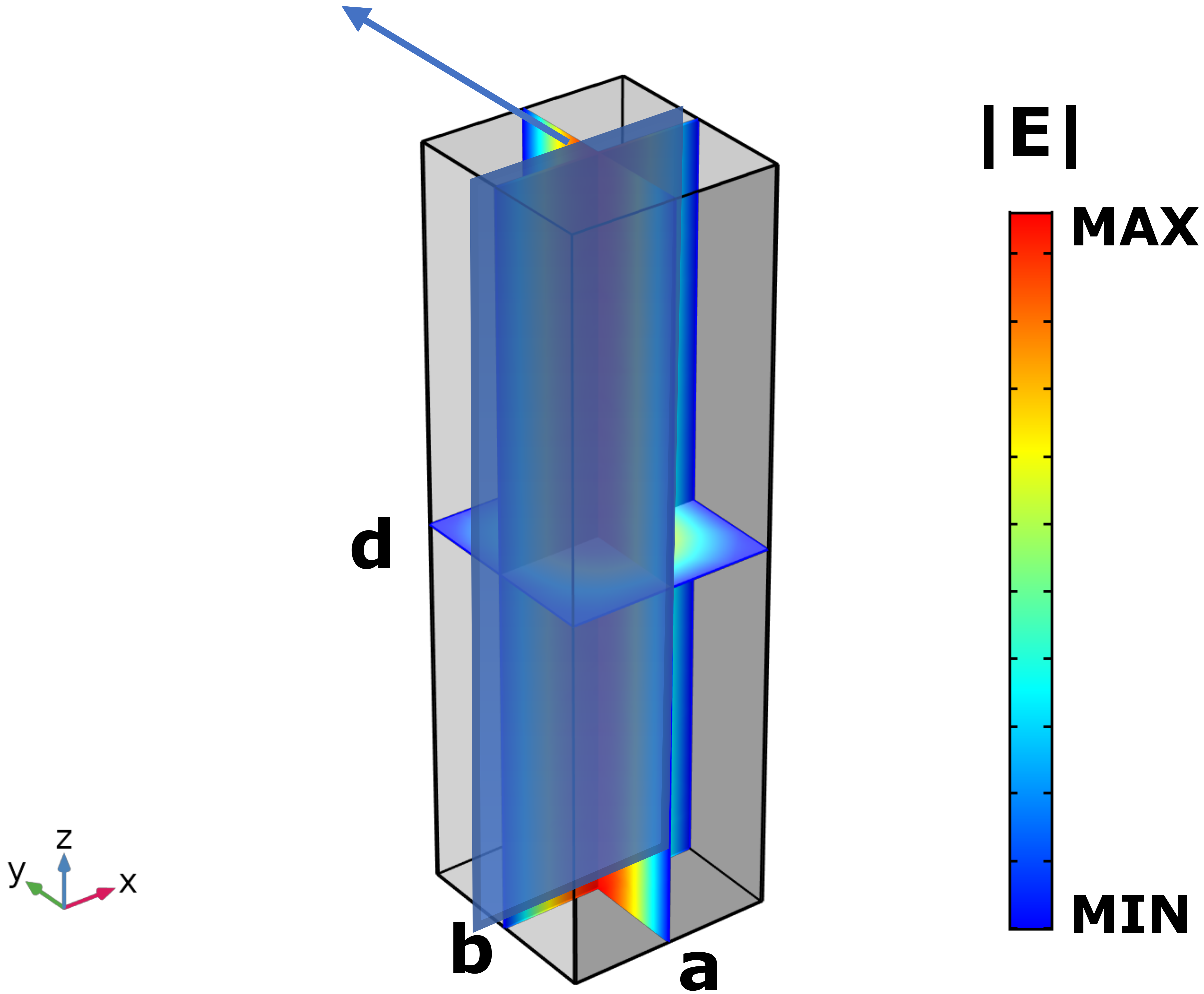
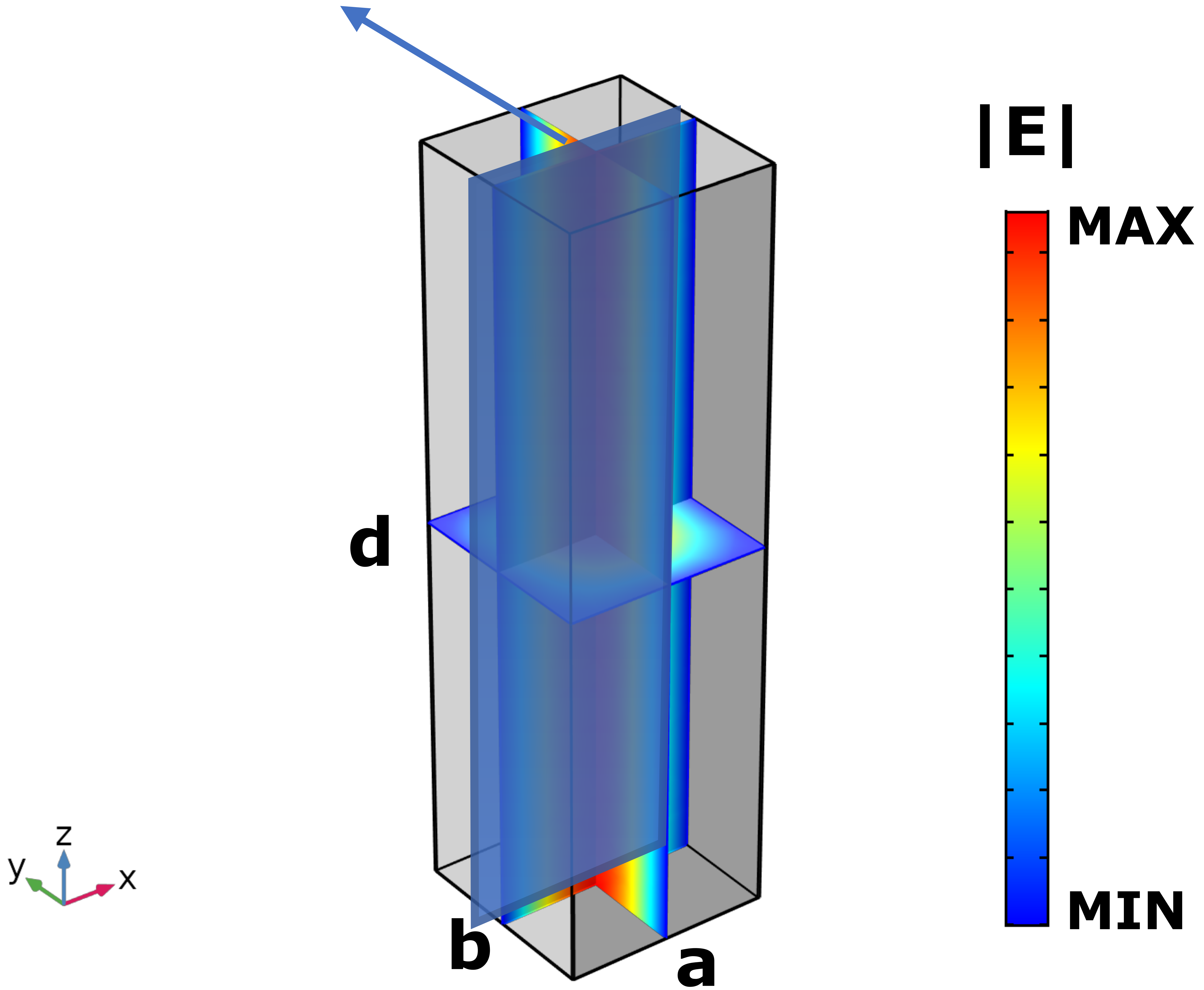


Phase 1b

- Simple idea by Ben McAllister
- New tunable rectangular cavity solves many problems!

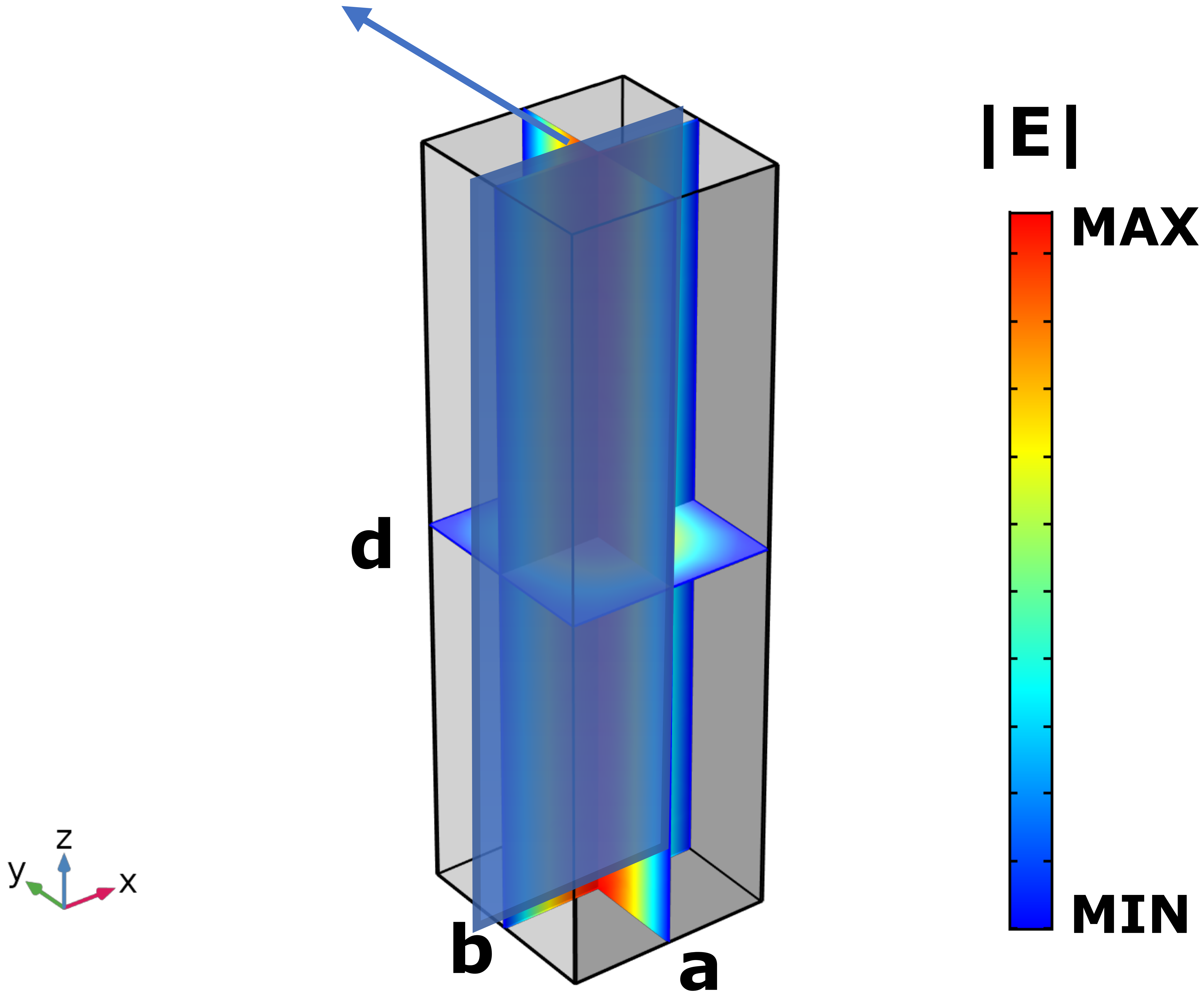


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1b

- Simple idea by Ben McAllister
- New tunable rectangular cavity solves many problems!

Parameter	Tuning-rod cavity	Rectangular cavity
C	❌	✅



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1b

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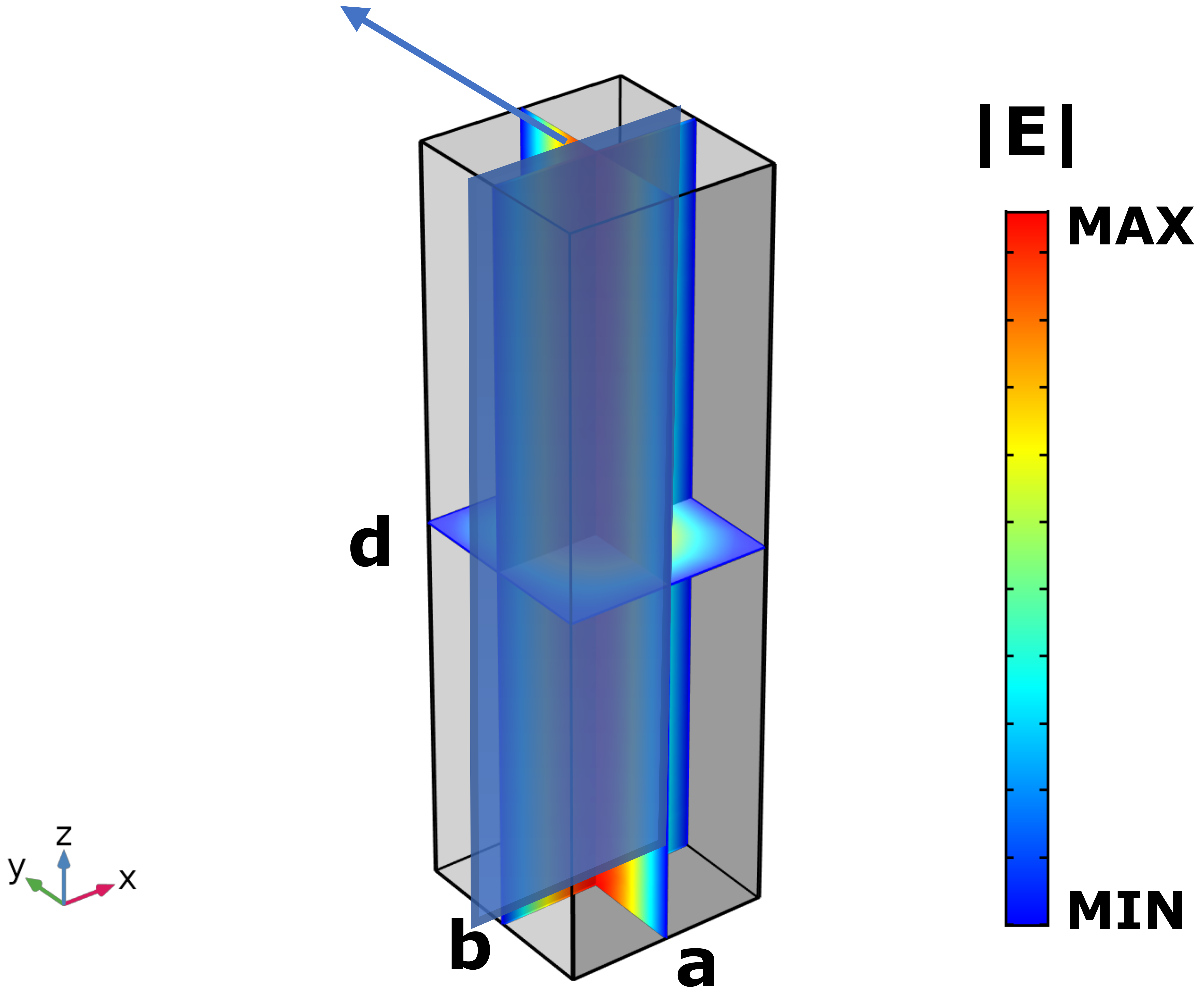
Parameter	Tuning-rod cavity	Rectangular cavity
C	❌	✅
Q	❌	✅



Phase 1b

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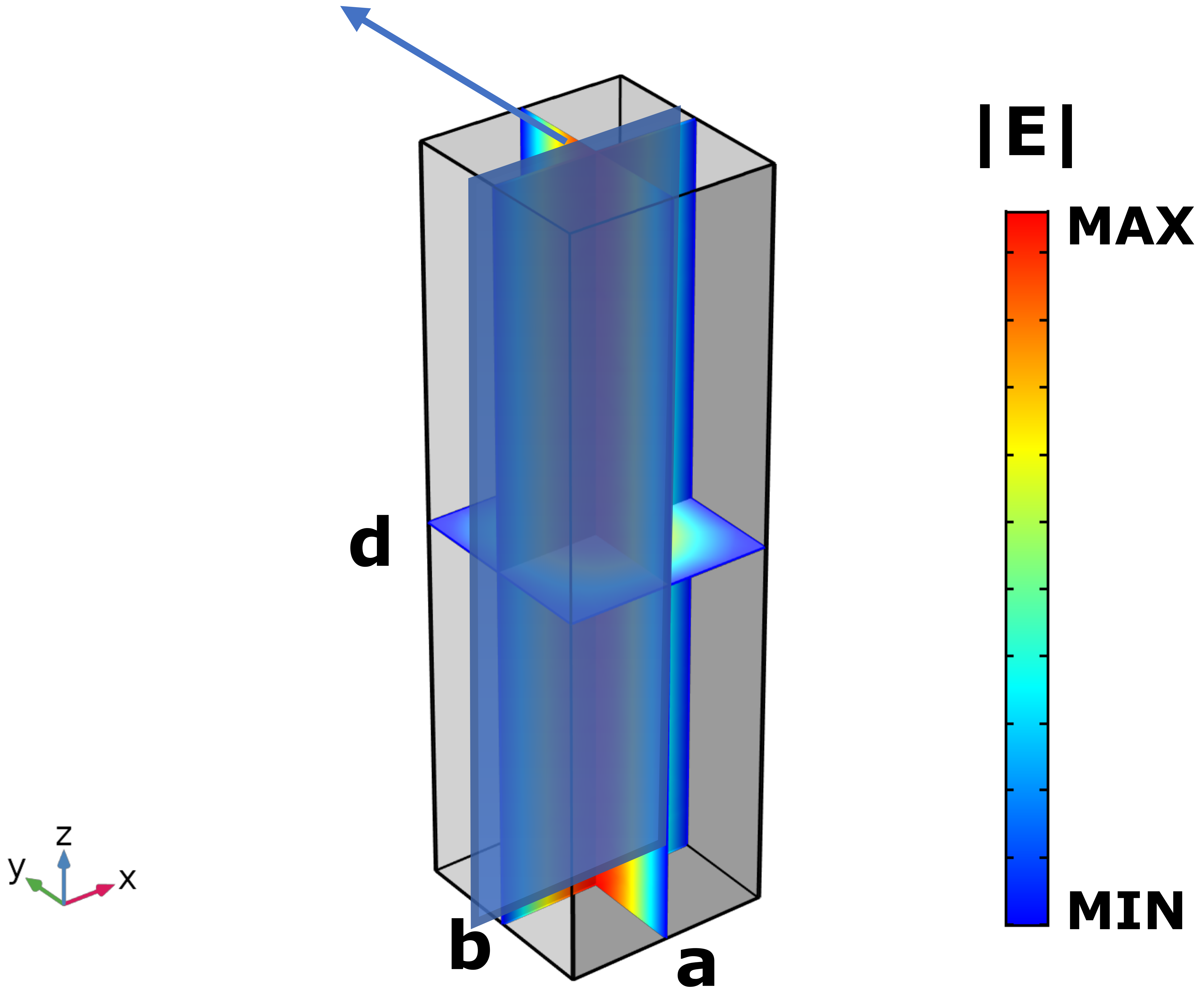
Parameter	Tuning-rod cavity	Rectangular cavity
C	❌	✅
Q	❌	✅
V	✅	❌



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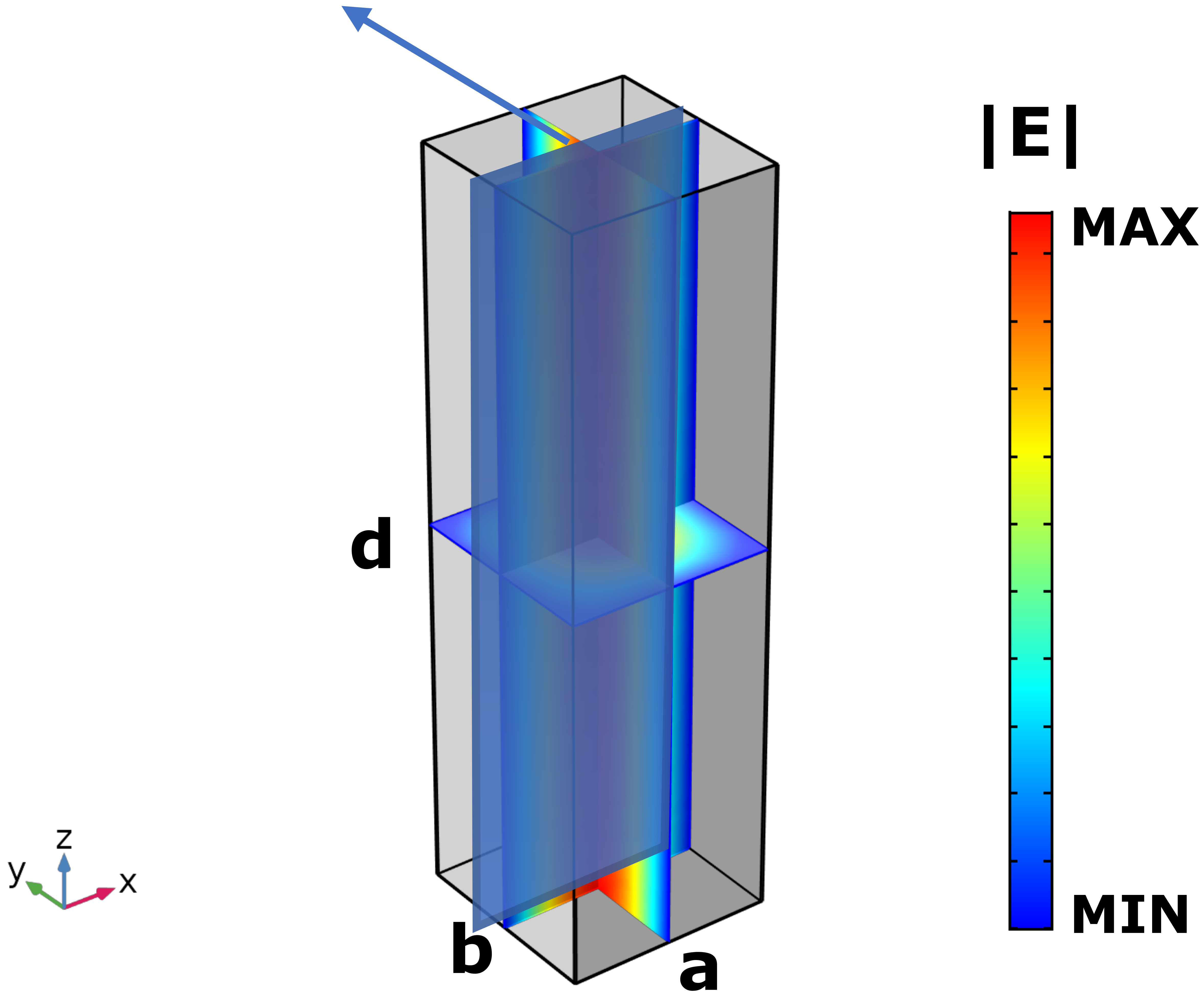
Parameter	Tuning-rod cavity	Rectangular cavity
C	❌	✅
Q	❌	✅
V	✅	❌
Mode crossings	❌	✅



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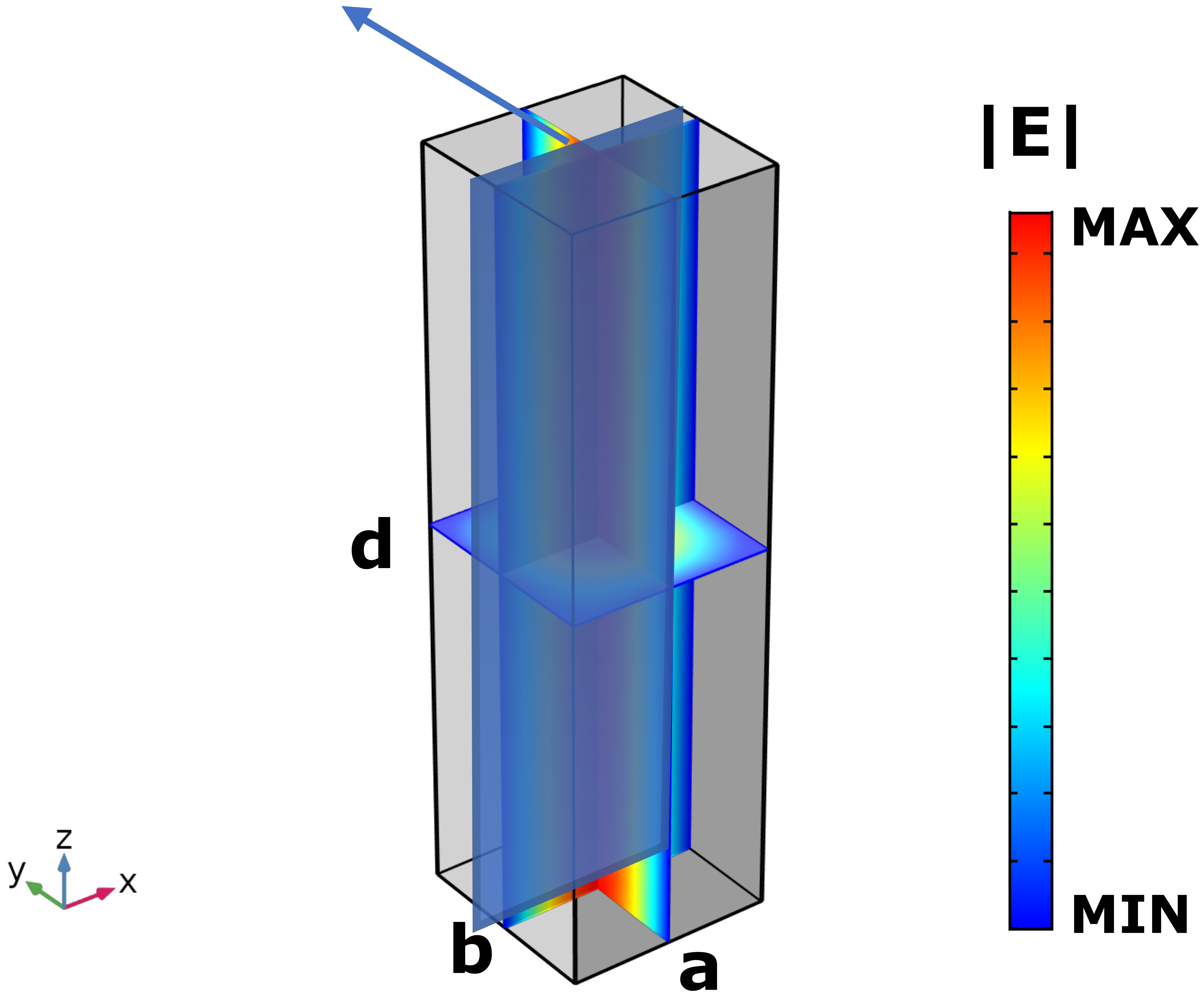
Parameter	Tuning-rod cavity	Rectangular cavity
C	❌	✅
Q	❌	✅
V	✅	❌
Mode crossings	❌	✅
Bore utilisation	✅	❌



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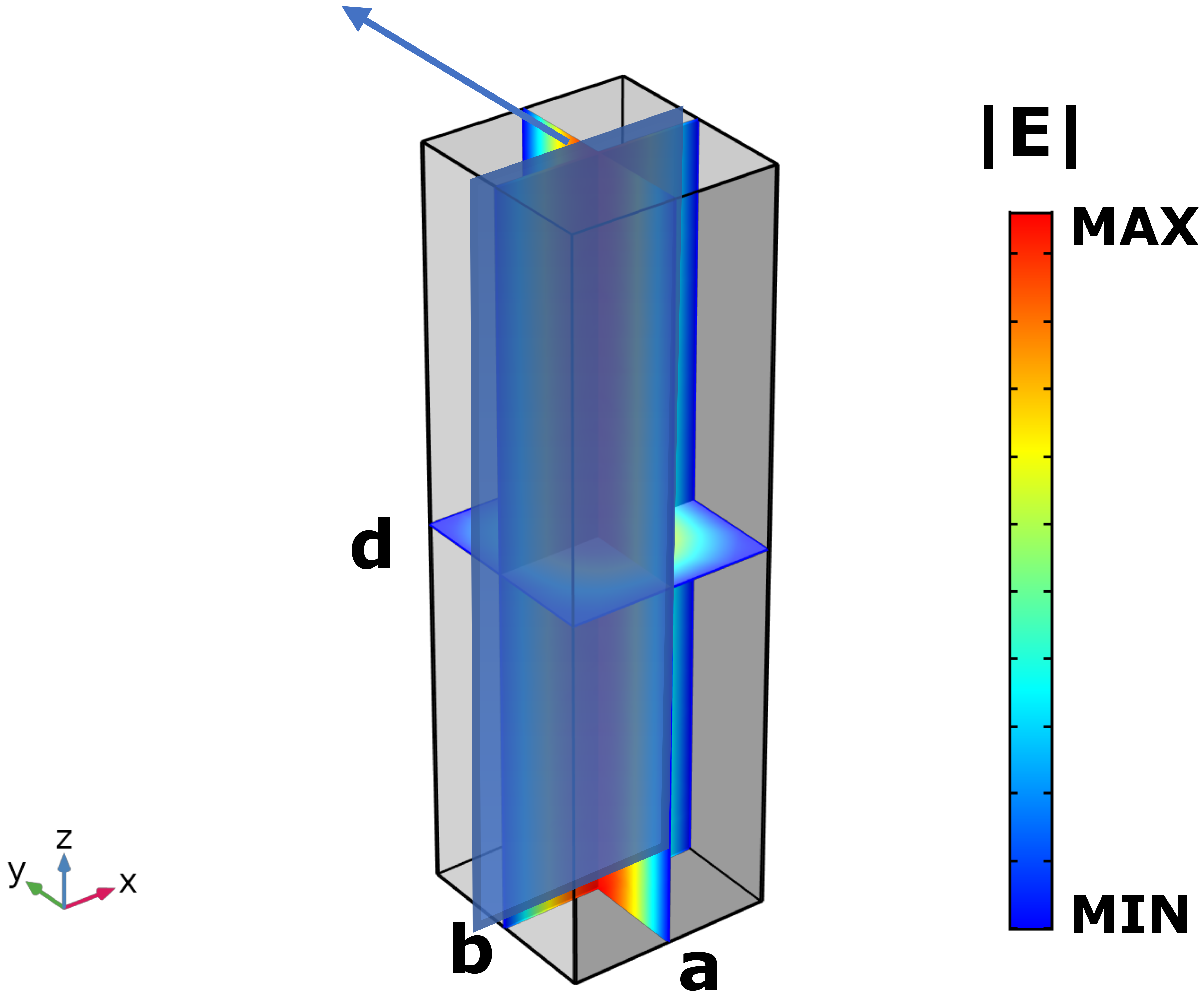
Parameter	Tuning-rod cavity	Rectangular cavity
C	❌	✅
Q	❌	✅
V	✅	❌
Mode crossings	❌	✅
Bore utilisation	✅	❌
Tuning	❌	✅✅



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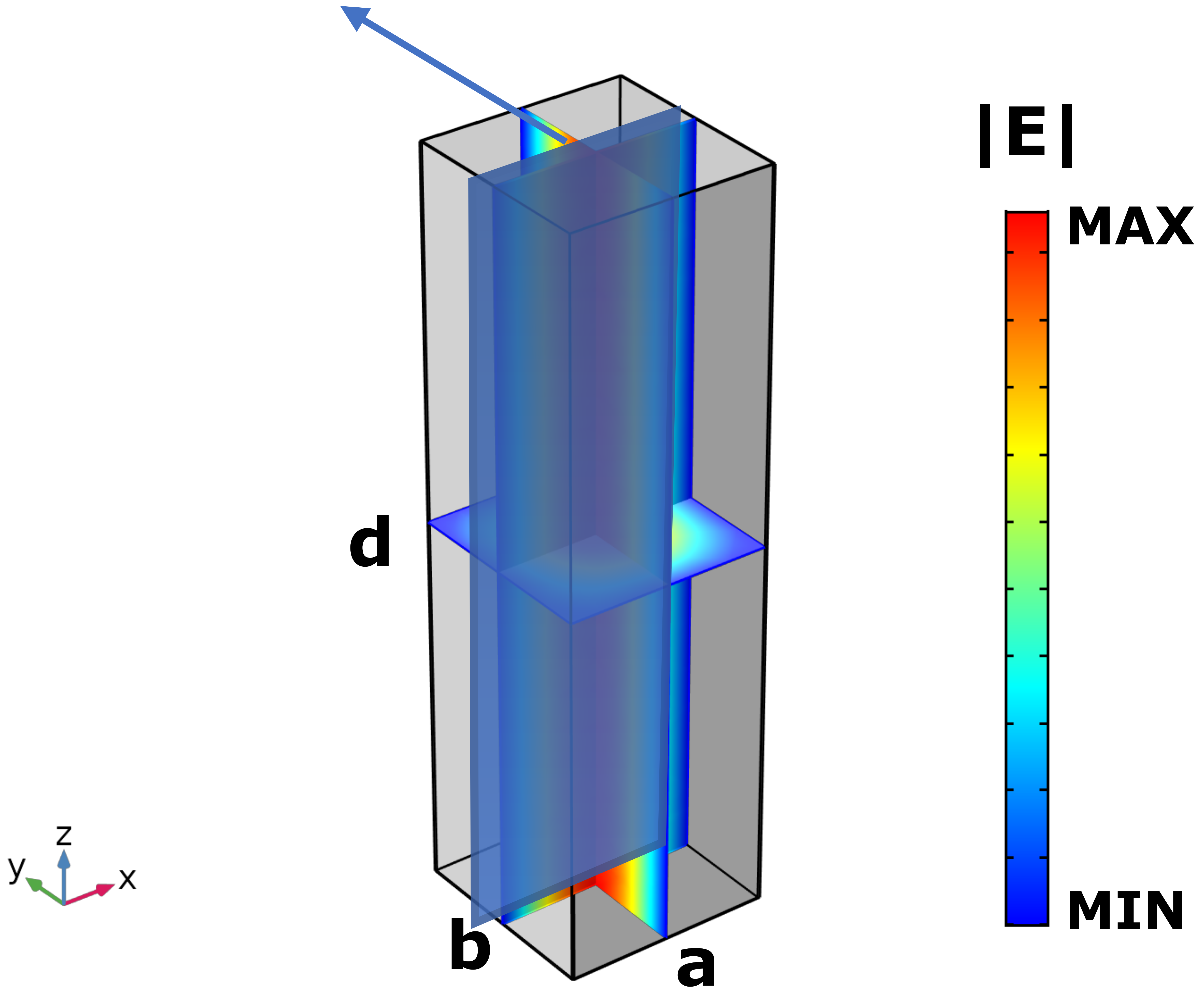
Parameter	Tuning-rod cavity	Rectangular cavity
C	❌	✅
Q	❌	✅
V	✅	❌
Mode crossings	❌	✅
Bore utilisation	✅	❌
Tuning	❌	✅✅
Scan rate	=	=/✅

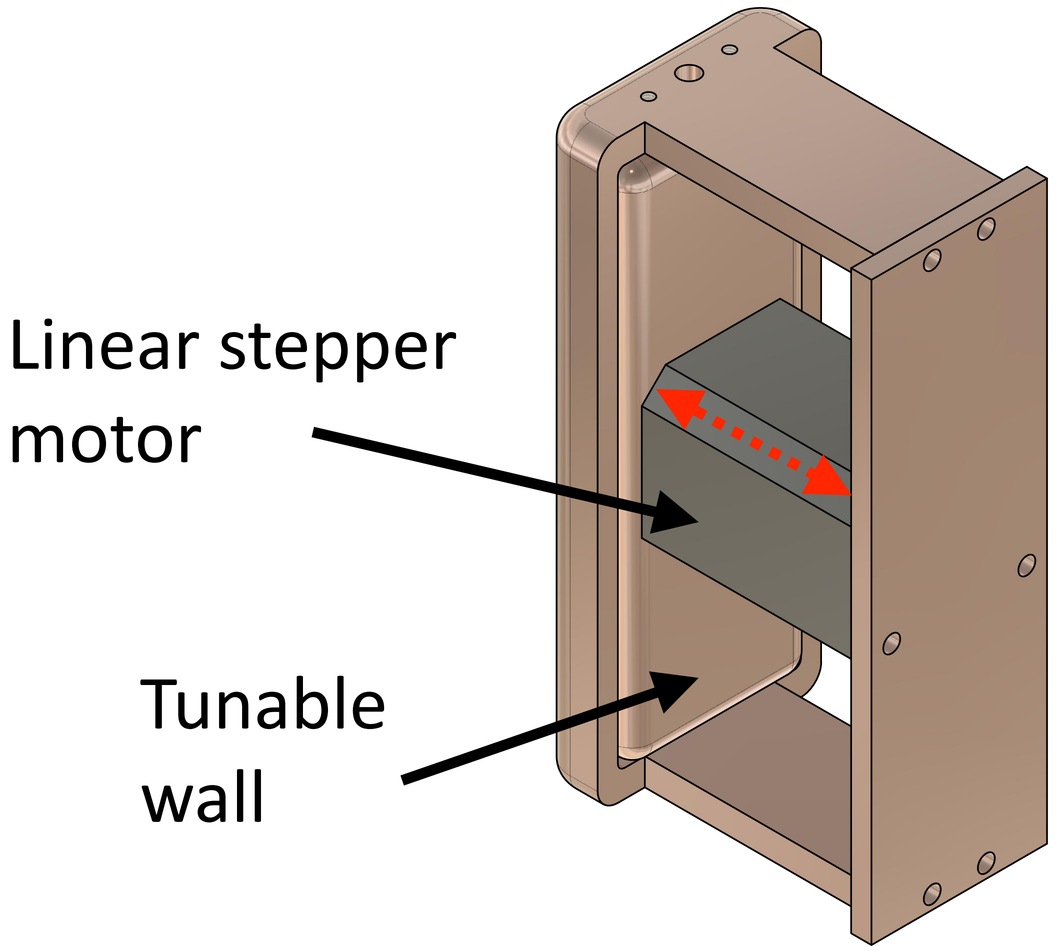


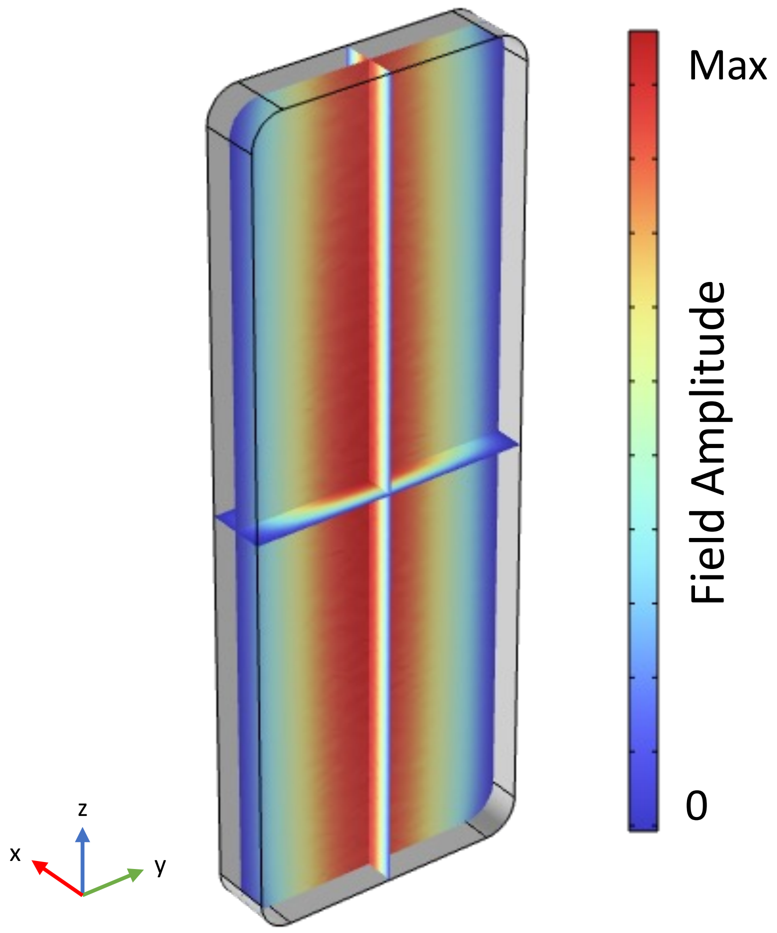
ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1b

Phase 1b

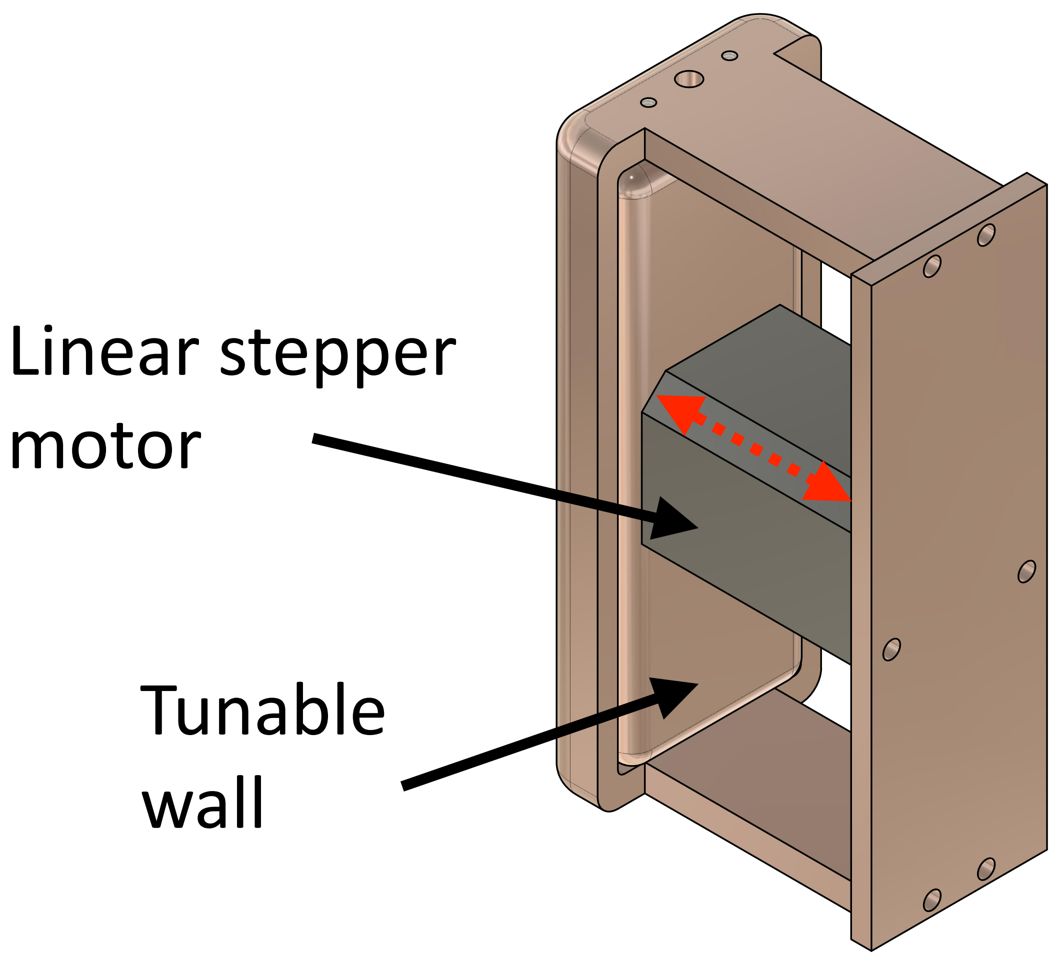
- First search already complete!

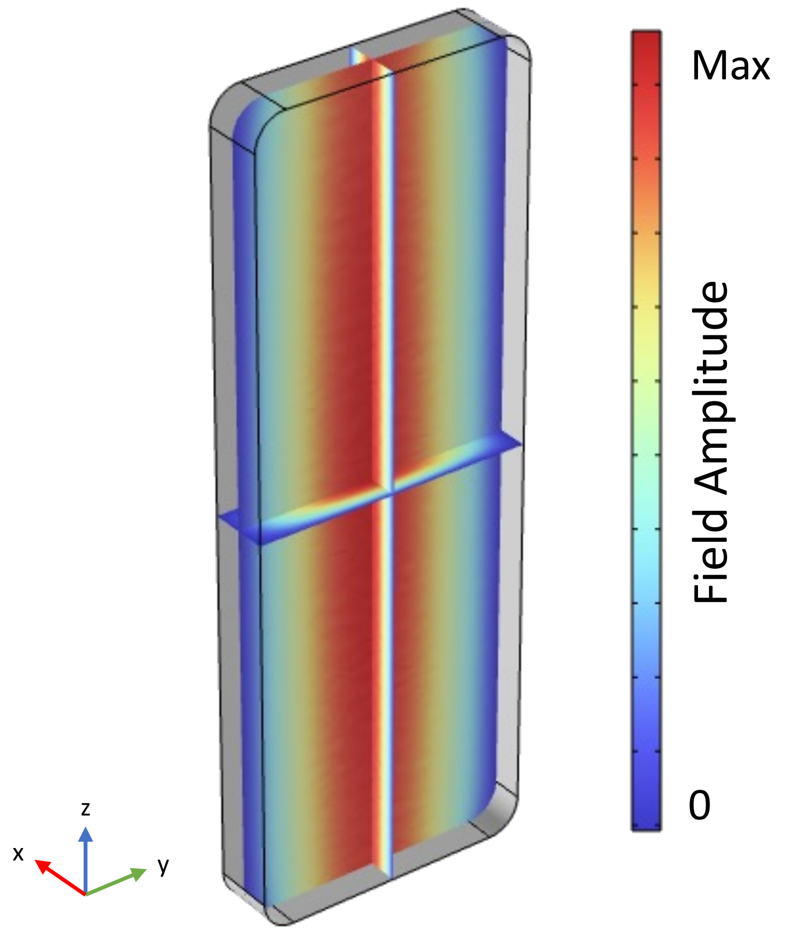


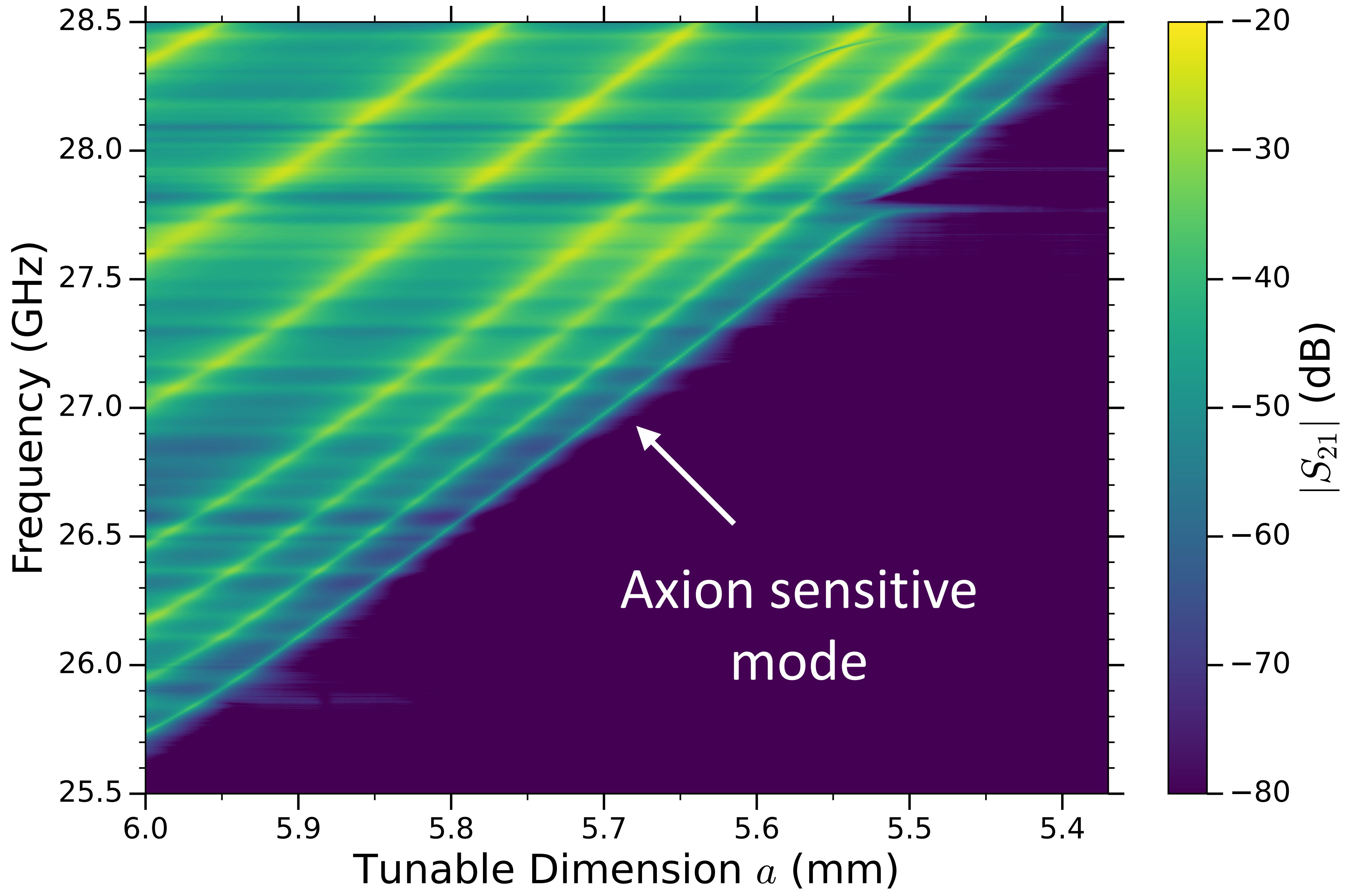


Phase 1b

- First search already complete!
- **<u>No</u>** mode crossings in 26-27 GHz target region!

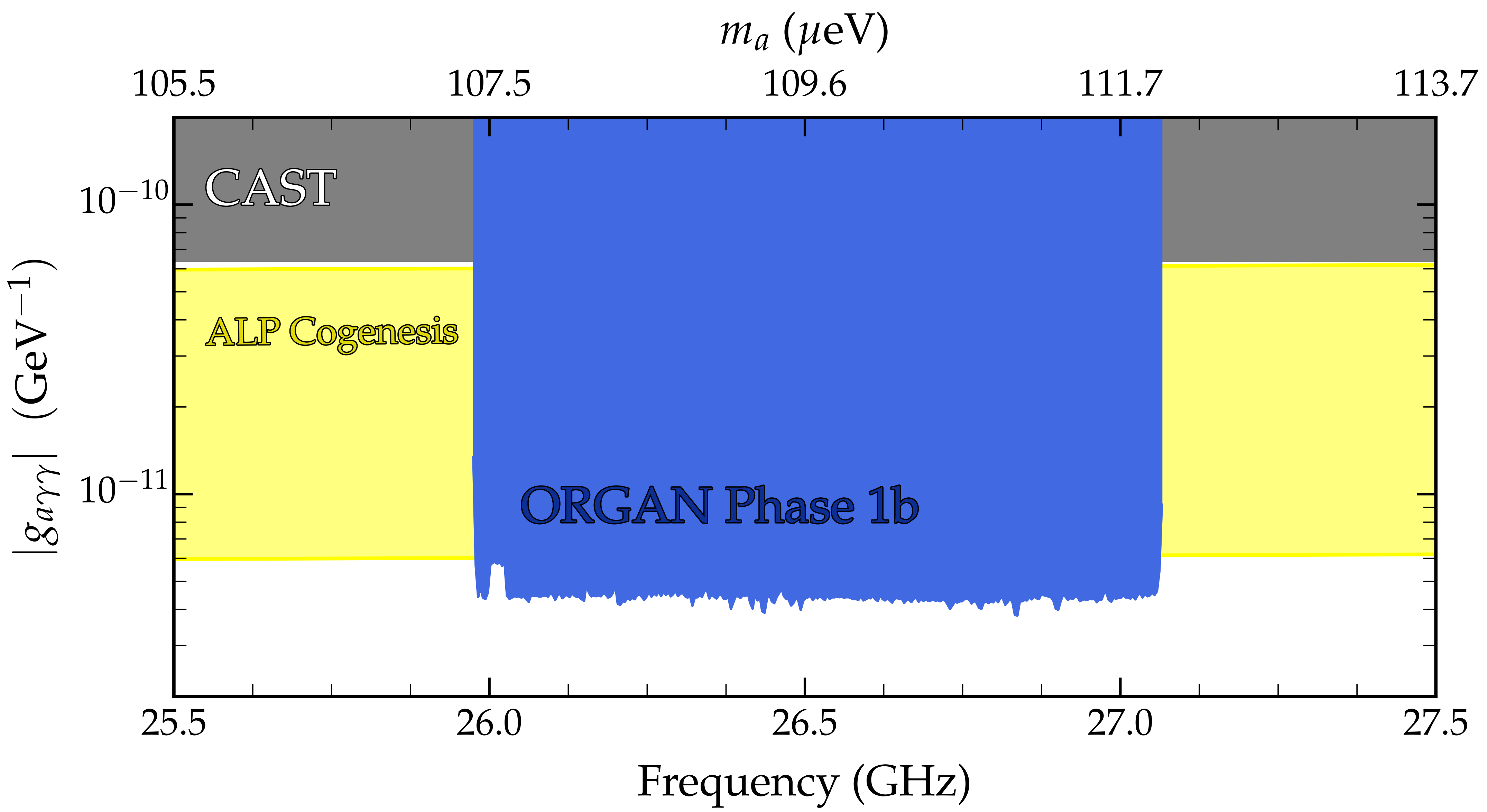


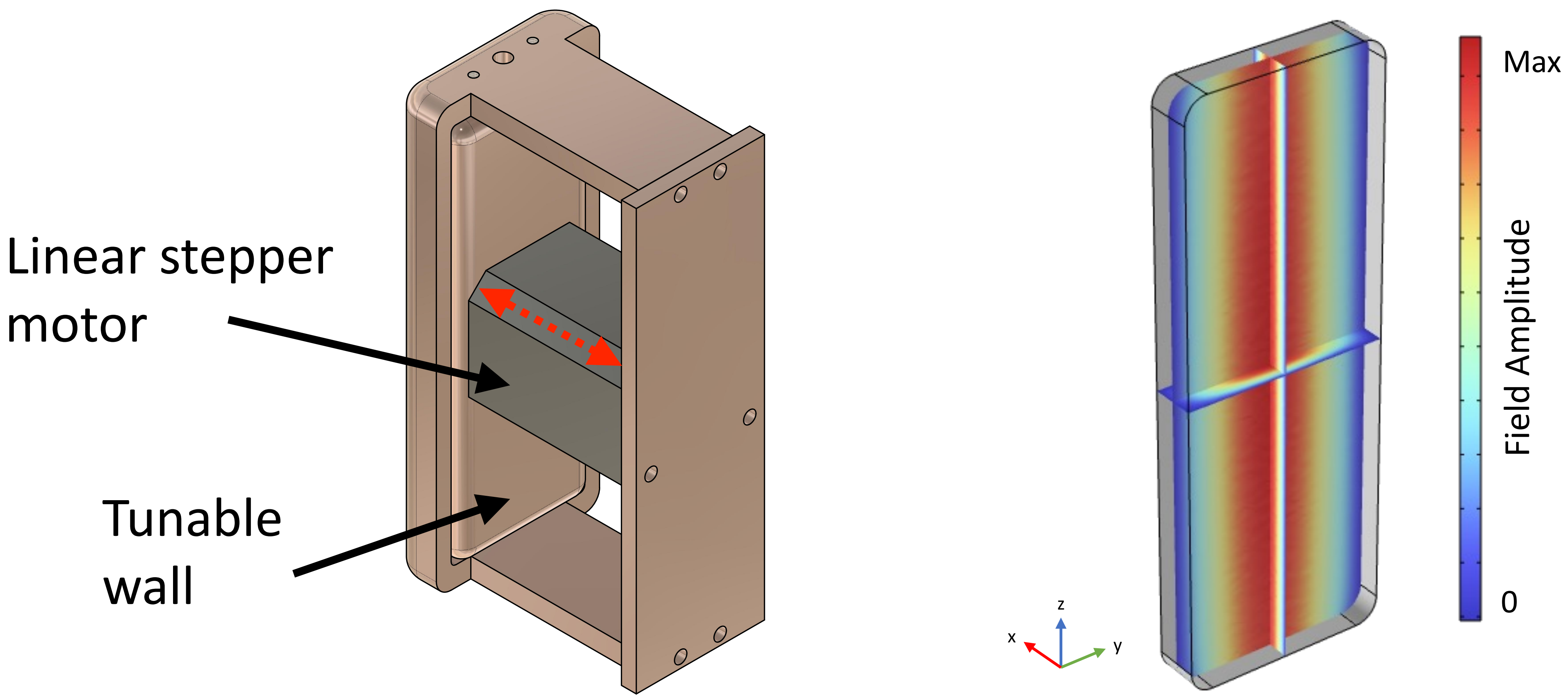


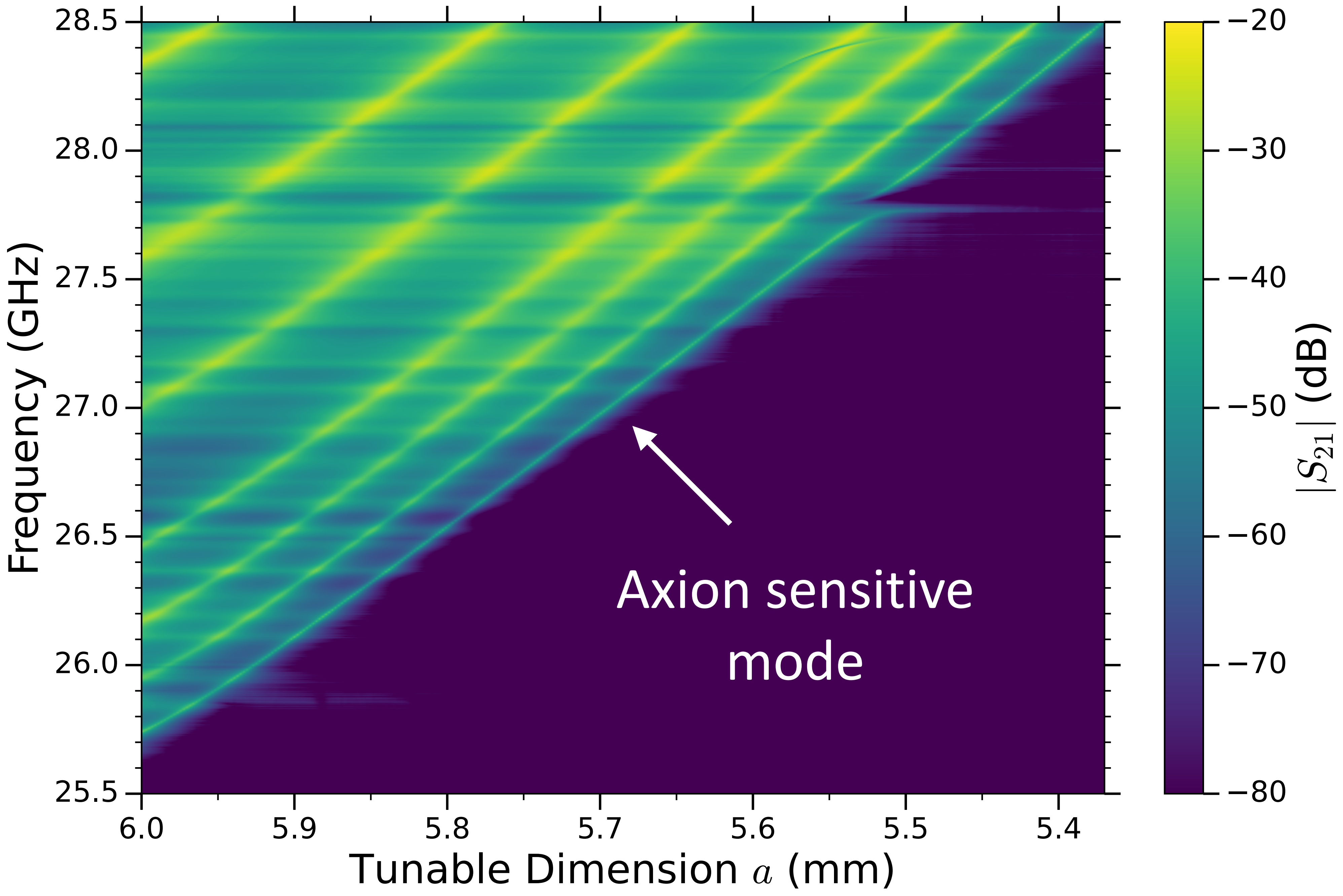


Phase 1b

- First search already complete!
- **No** mode crossings in 26-27 GHz target region!
- Most sensitive high mass axion search yet!







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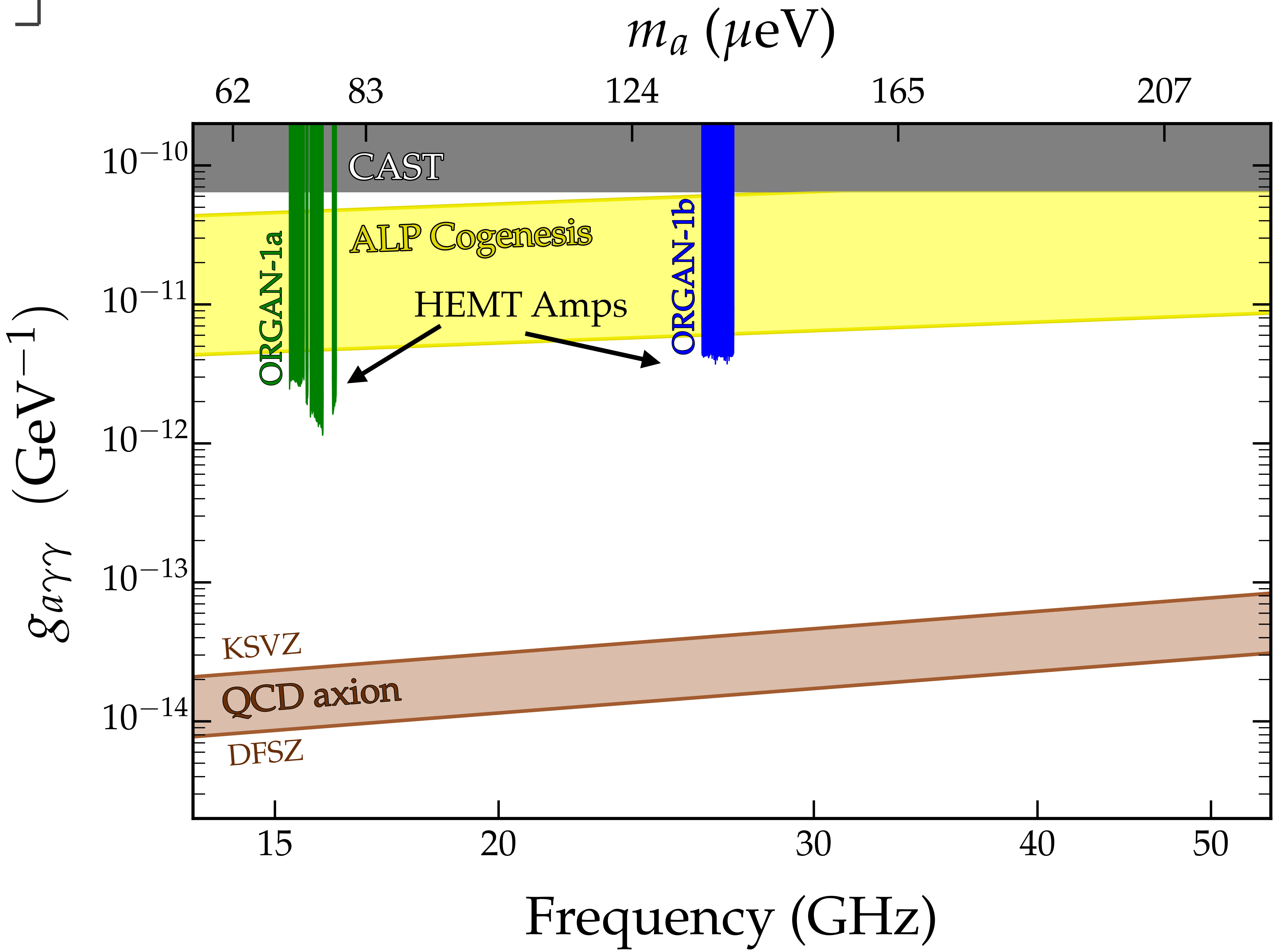
ORGAN Run Plan

Phase 1

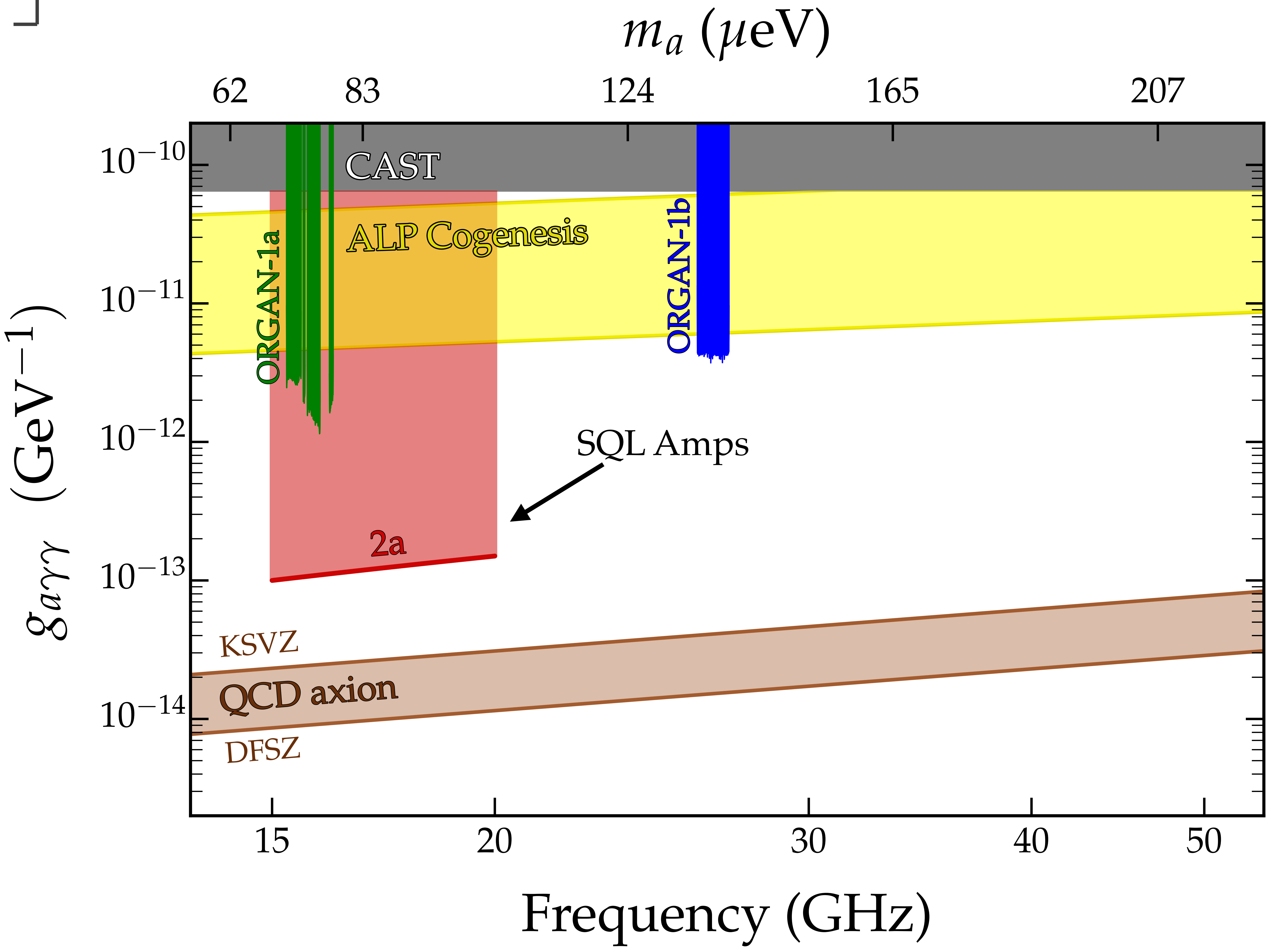
- Targeted searches between 15-16 GHz and 26-27 GHz ~ month scale



ORGAN Run Plan

Phase 2a

- Wider search (15-20 GHz) building on current expertise ~ year scale
- Move to mK temperatures and Standard Quantum Limited (SQL) ampifiers



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

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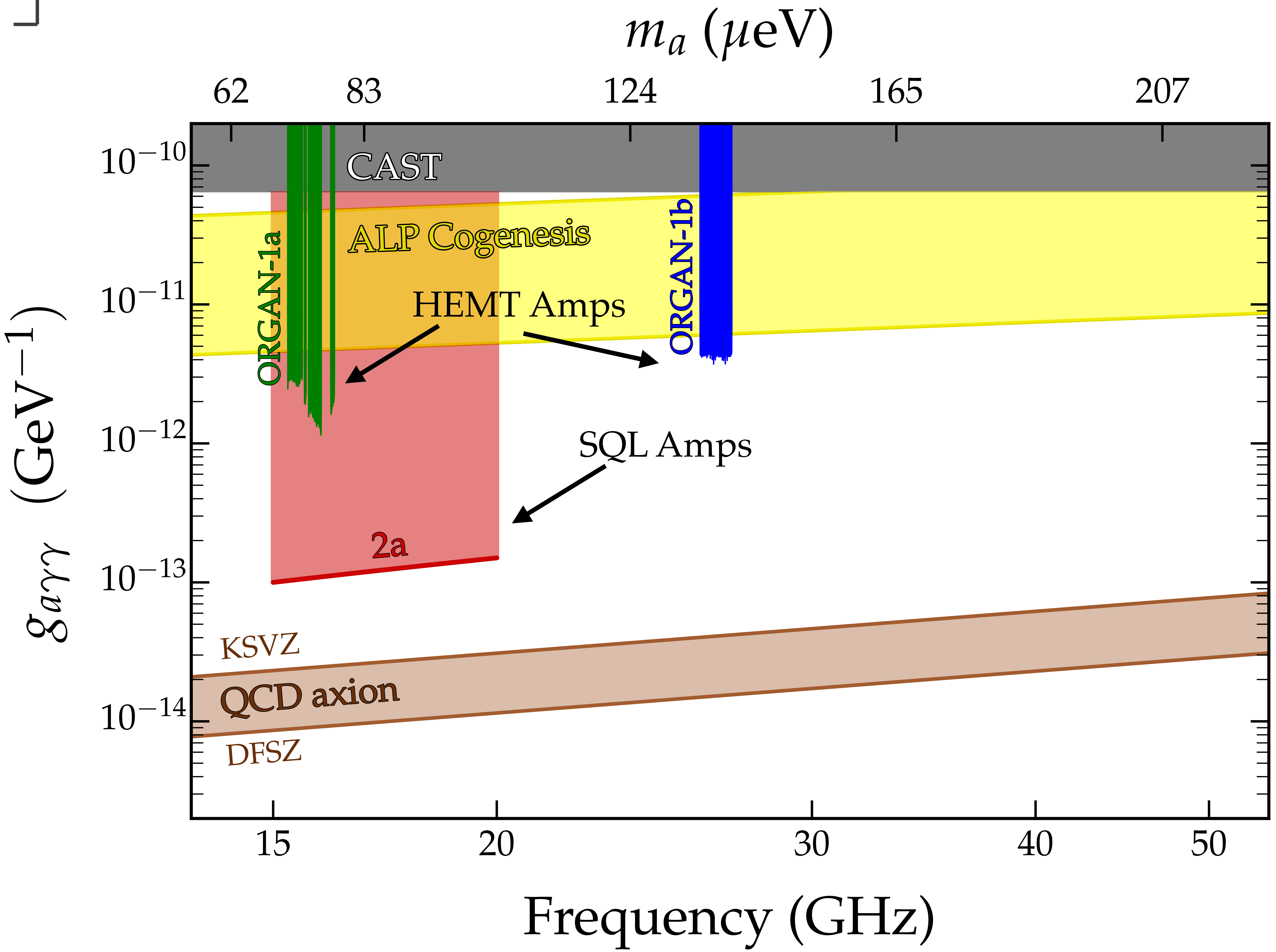
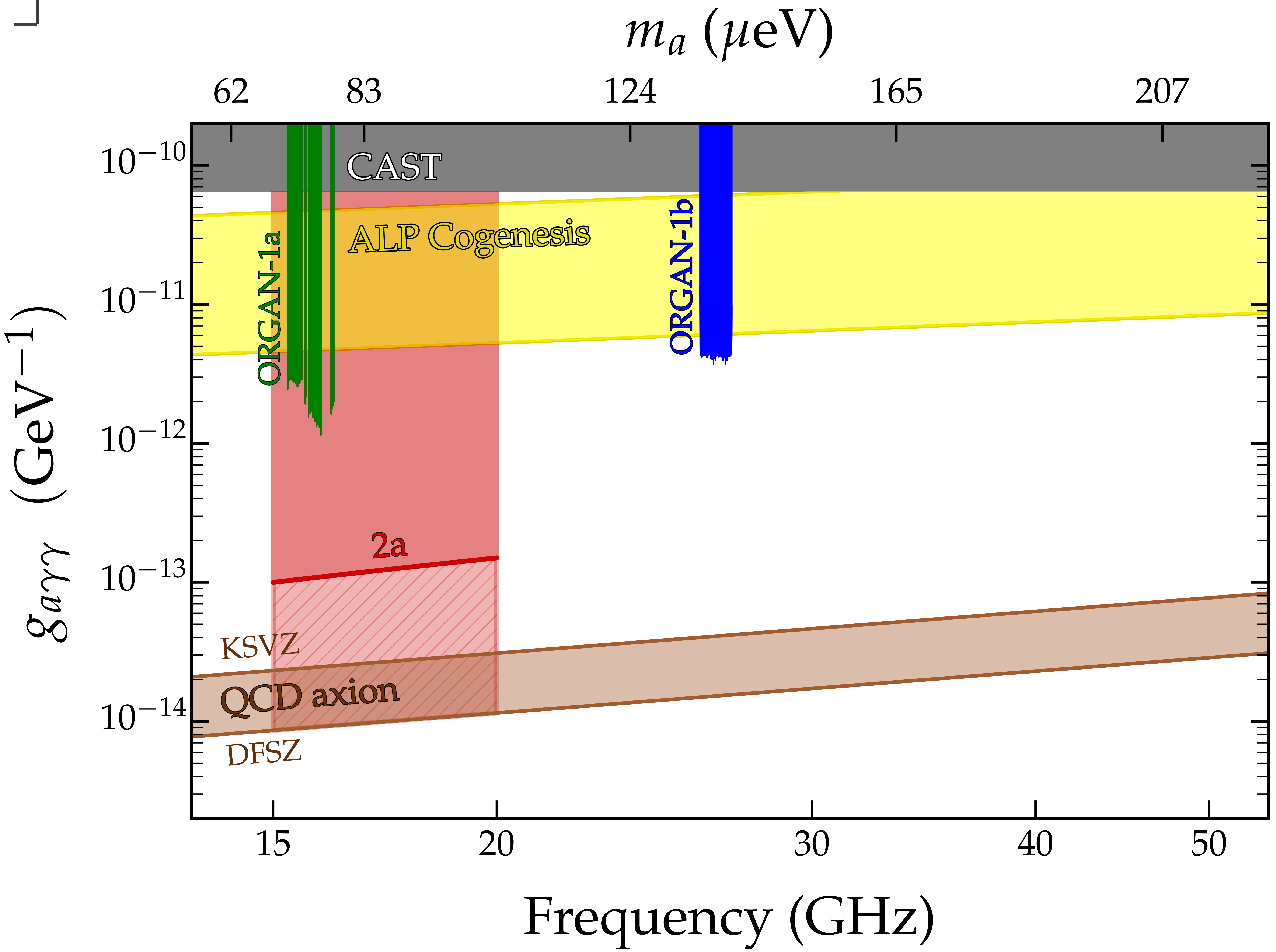


ORGAN Run Plan

Phase 2a

- Develop efficent single photon counting (SPC) devices
- Reach **QCD axion** model bands



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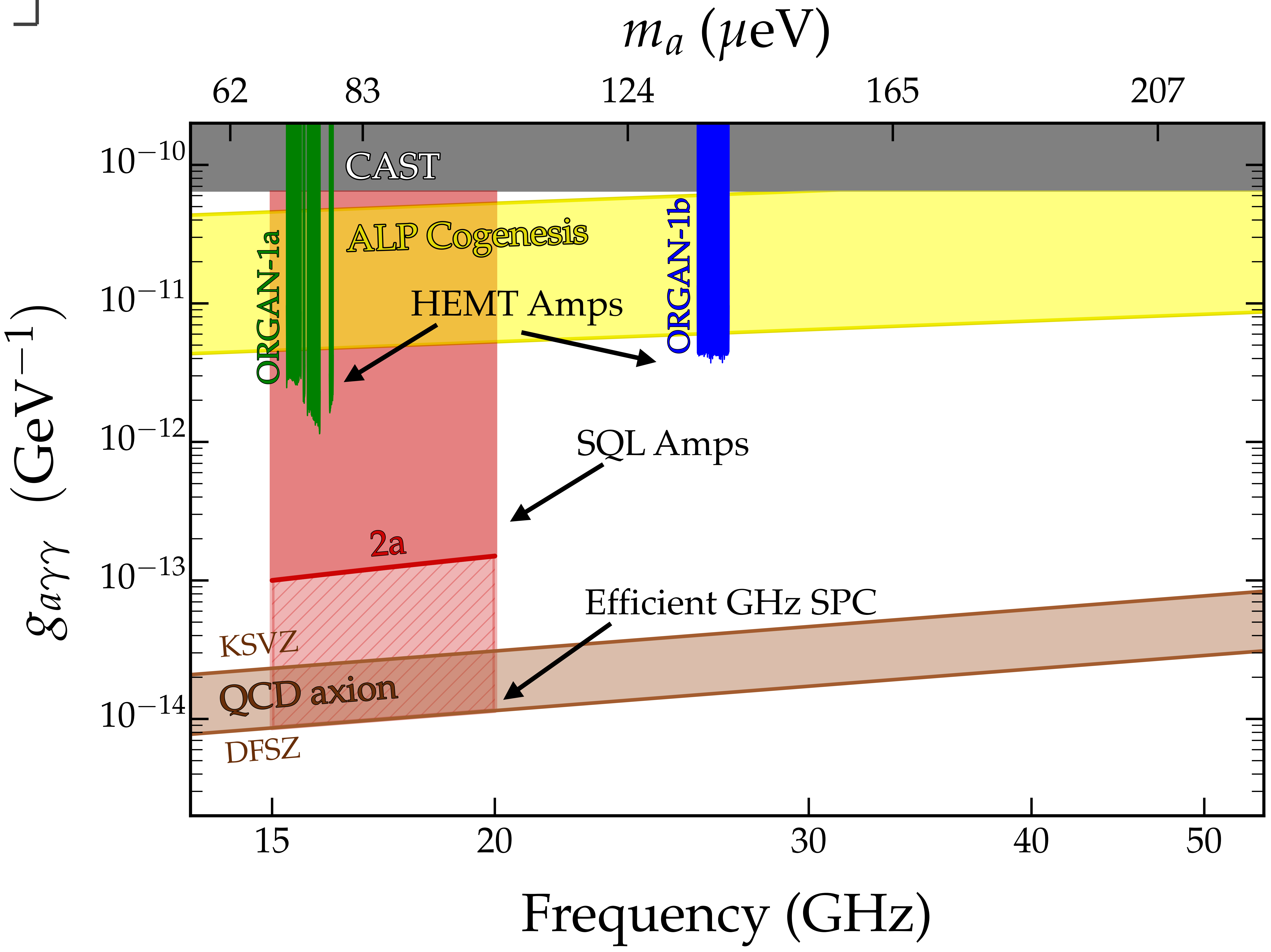

ORGAN-Q

(A quick detour..)

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ORGAN-Q

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- Q → Quantum

ORGAN-Q

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- Utilises a **Joshephson Parametric Amplifier** (JPA): ↓ T_s

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(A quick detour..)

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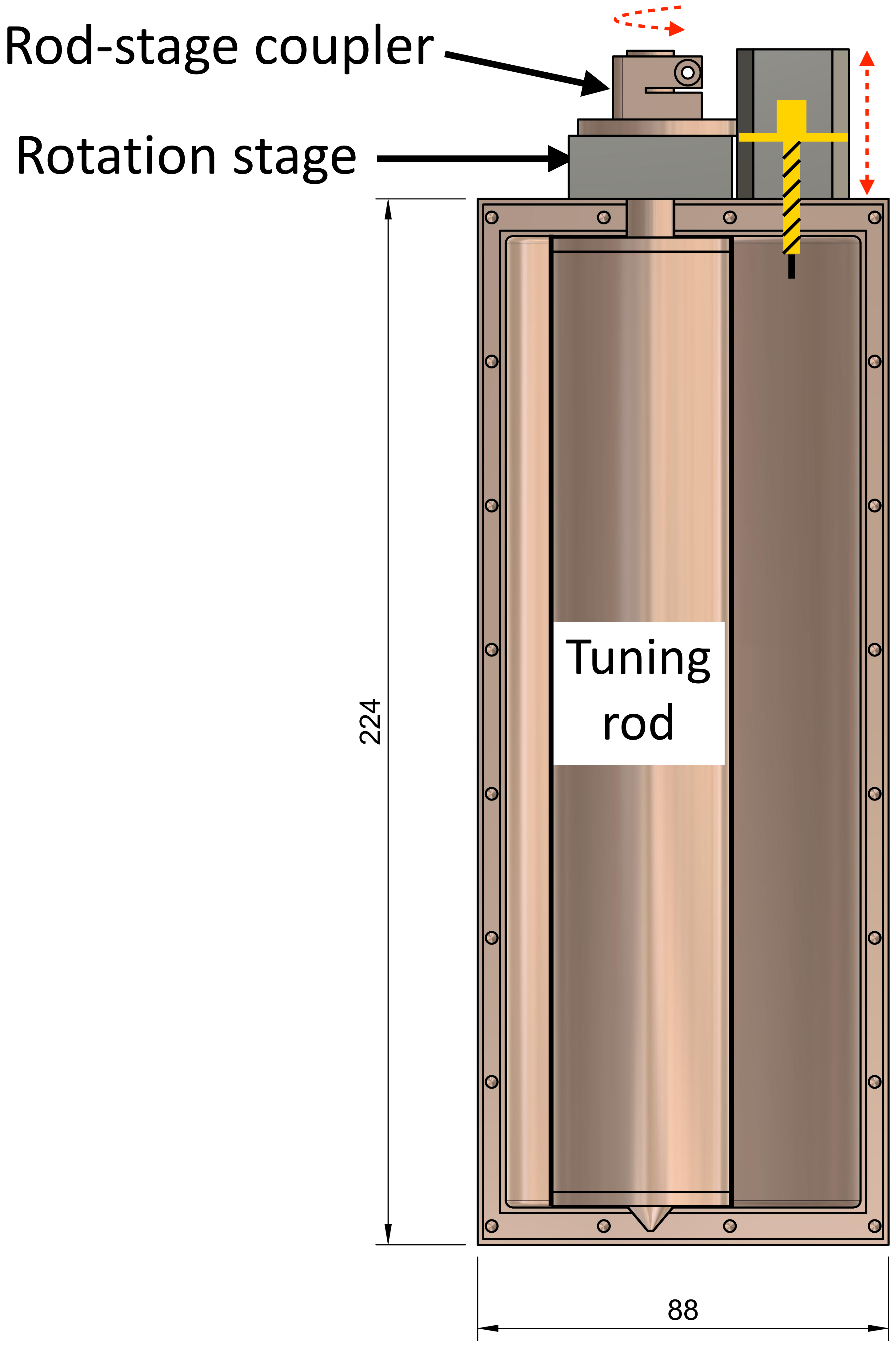


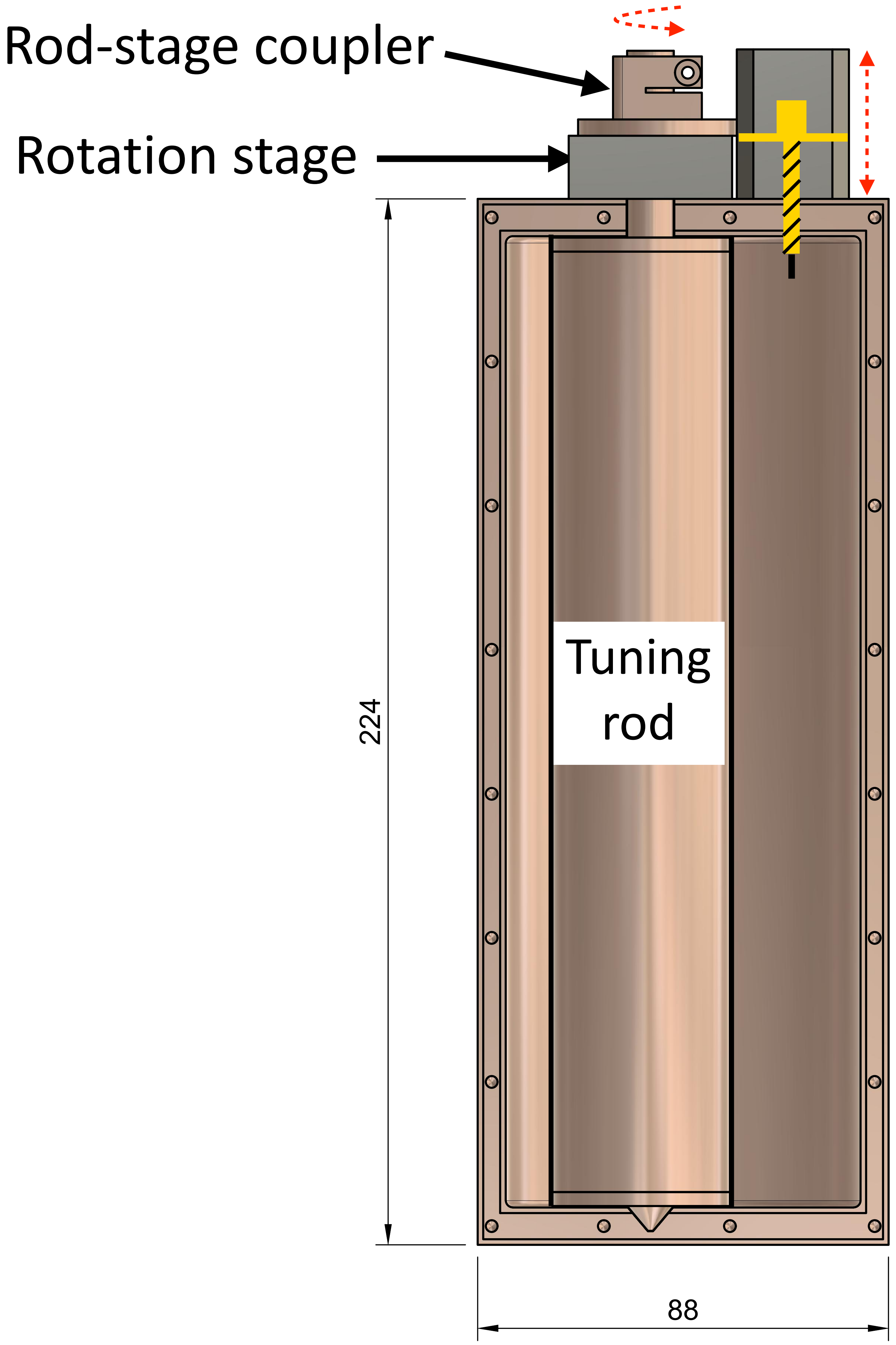
ORGAN-Q

(A quick detour..)

- Q → Quantum

- Utilises a **Joshephson Parametric Amplifier** (JPA): $\downarrow T_s$

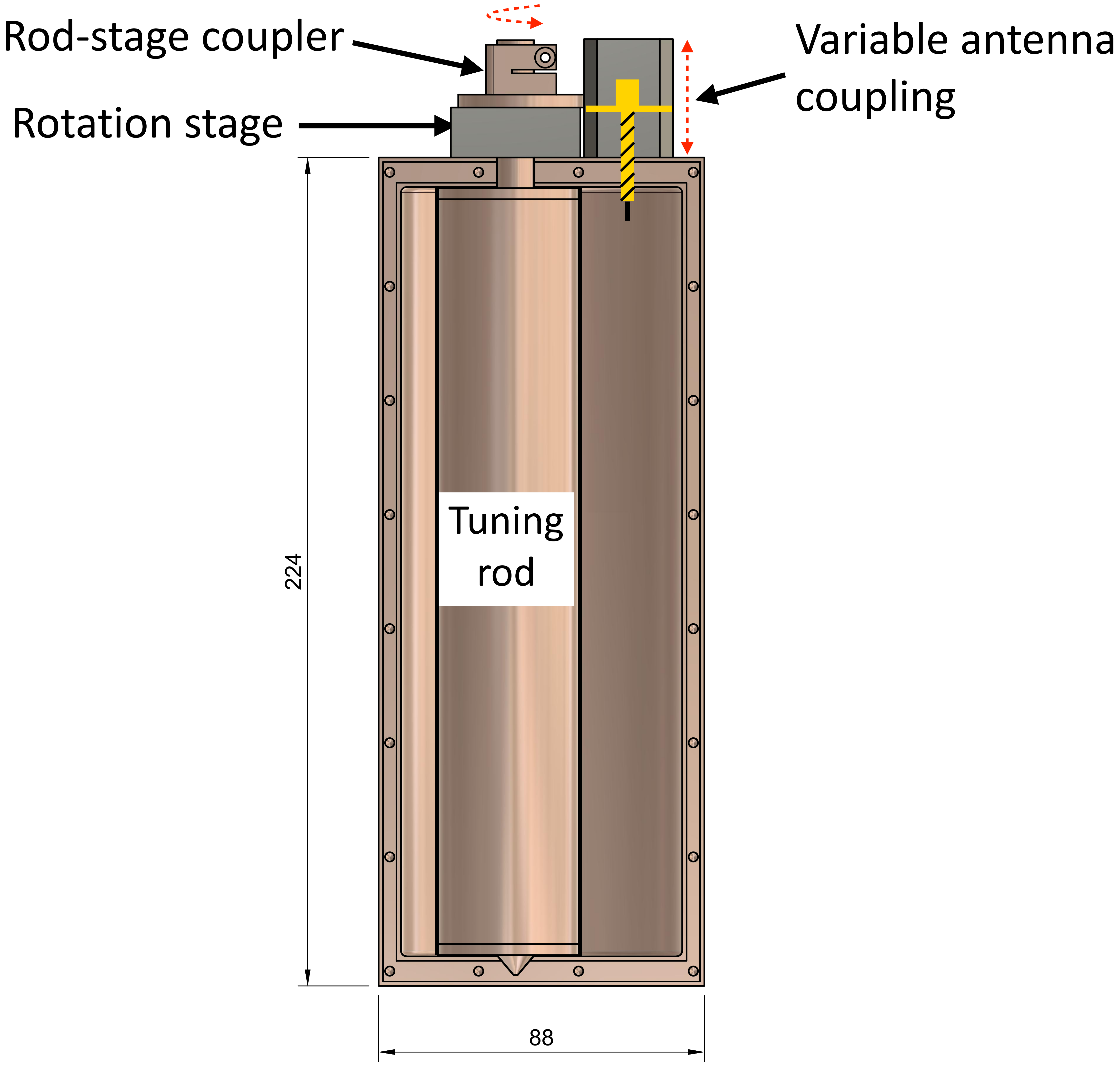
- Operates at mK: $\downarrow T_s$



ORGAN-Q

(A quick detour..)

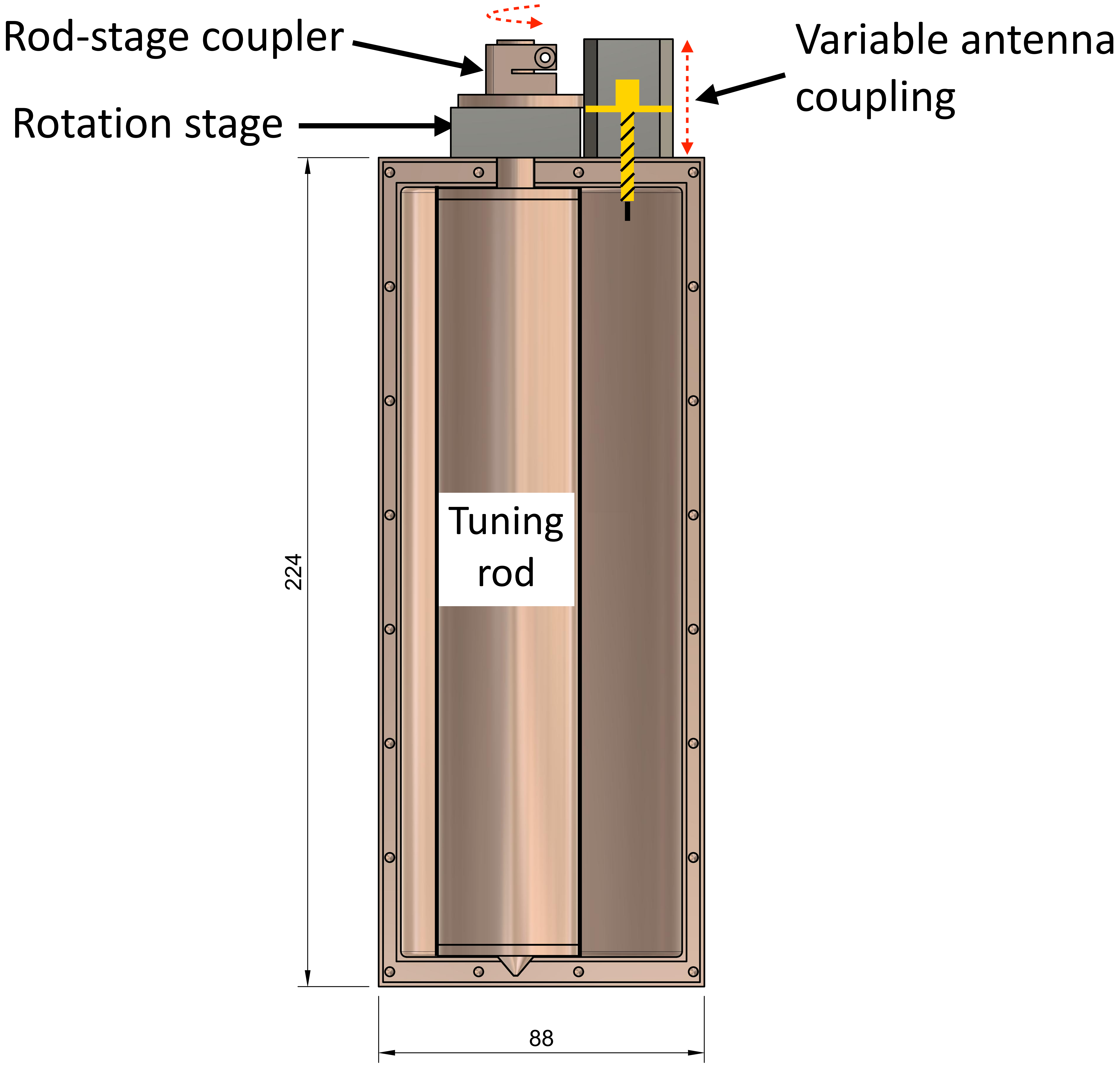
- Q → Quantum
- Utilises a **Joshephson Parametric Amplifier** (JPA): ↓ T_s
- Operates at mK: ↓ T_s
- Variable coupling: ↑ $Q_L \dfrac{\beta^2}{(1+\beta)^2}$



ORGAN-Q

(A quick detour..)

- Q → Quantum
- Utilises a **Joshephson Parametric Amplifier** (JPA): $\downarrow T_s$
- Operates at mK: $\downarrow T_s$
- Variable coupling: $\uparrow Q_{\mathrm{L}} \dfrac{\beta^2}{(1+\beta)^2}$
- Plan for 5-10 x KSVZ sensitivity



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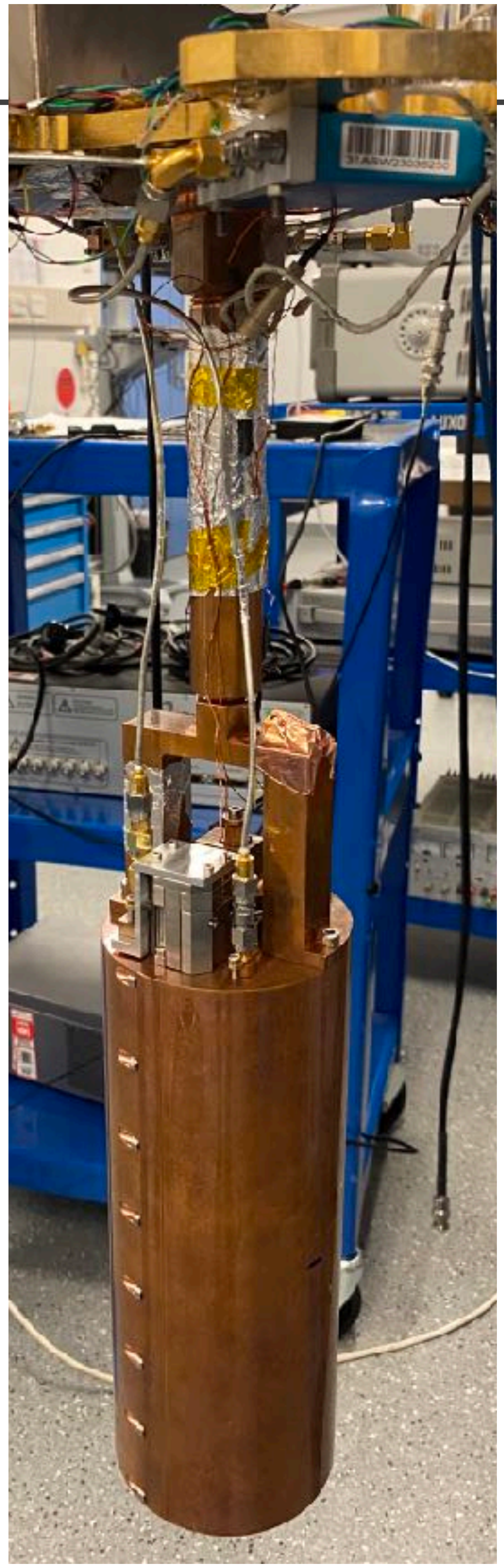

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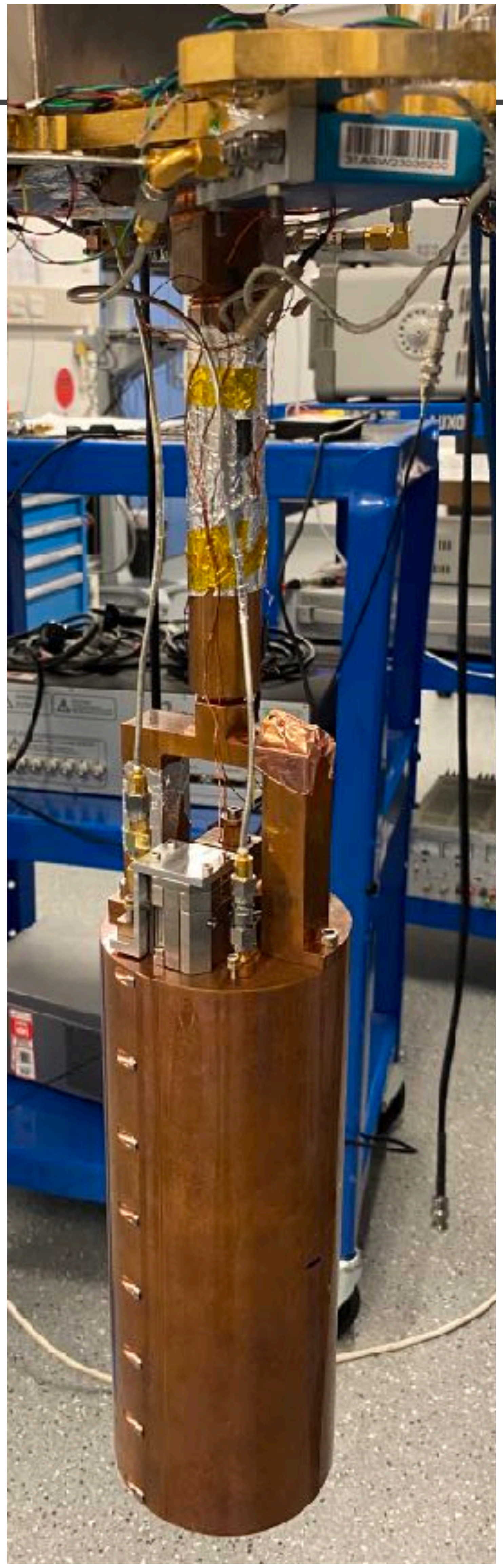

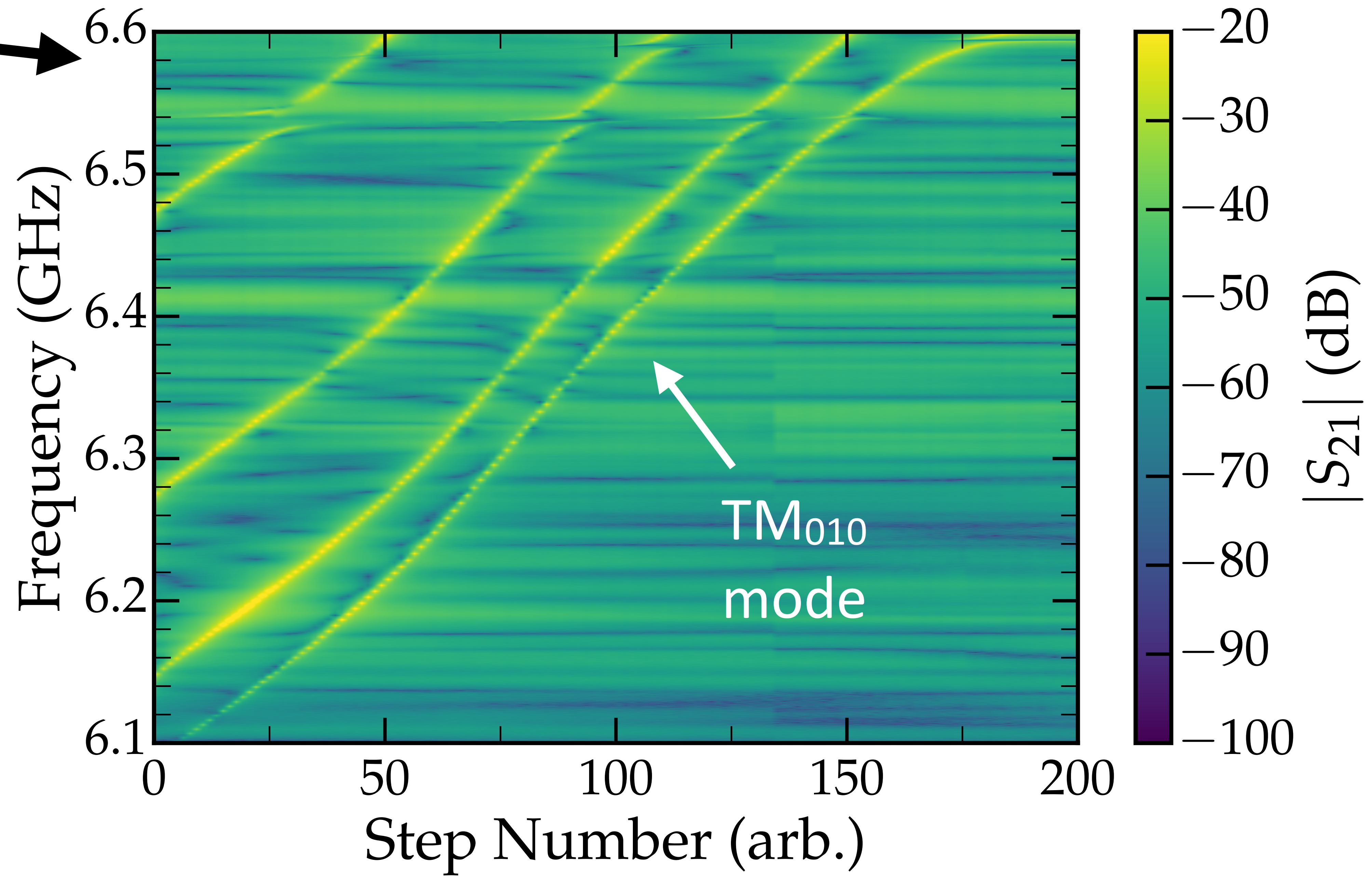

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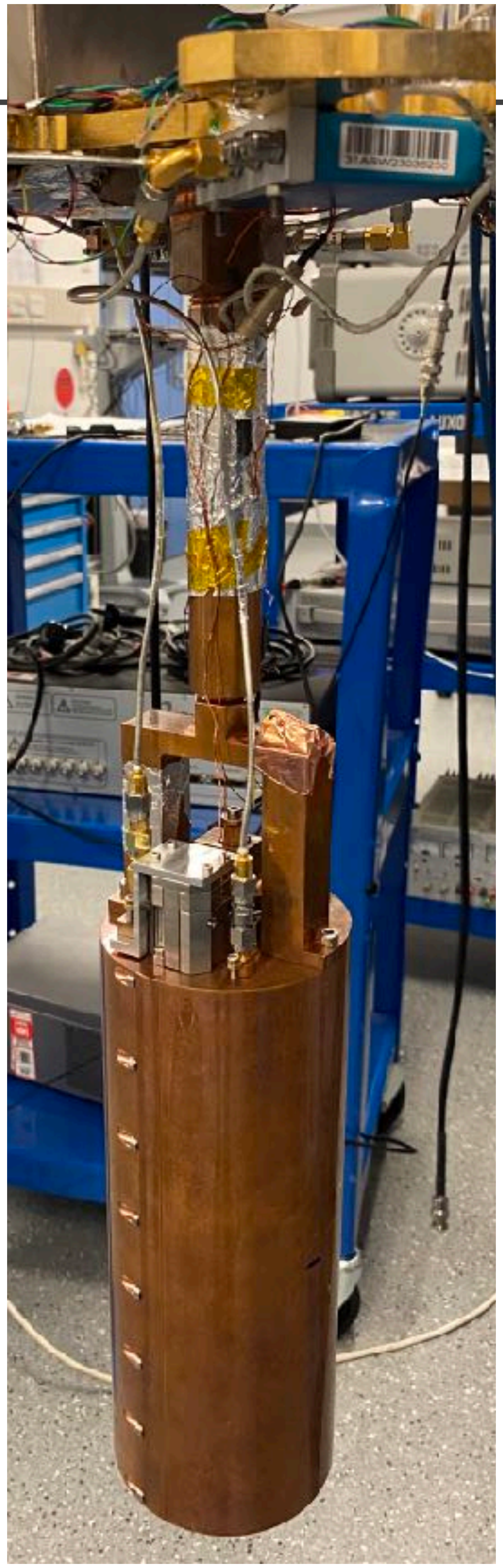

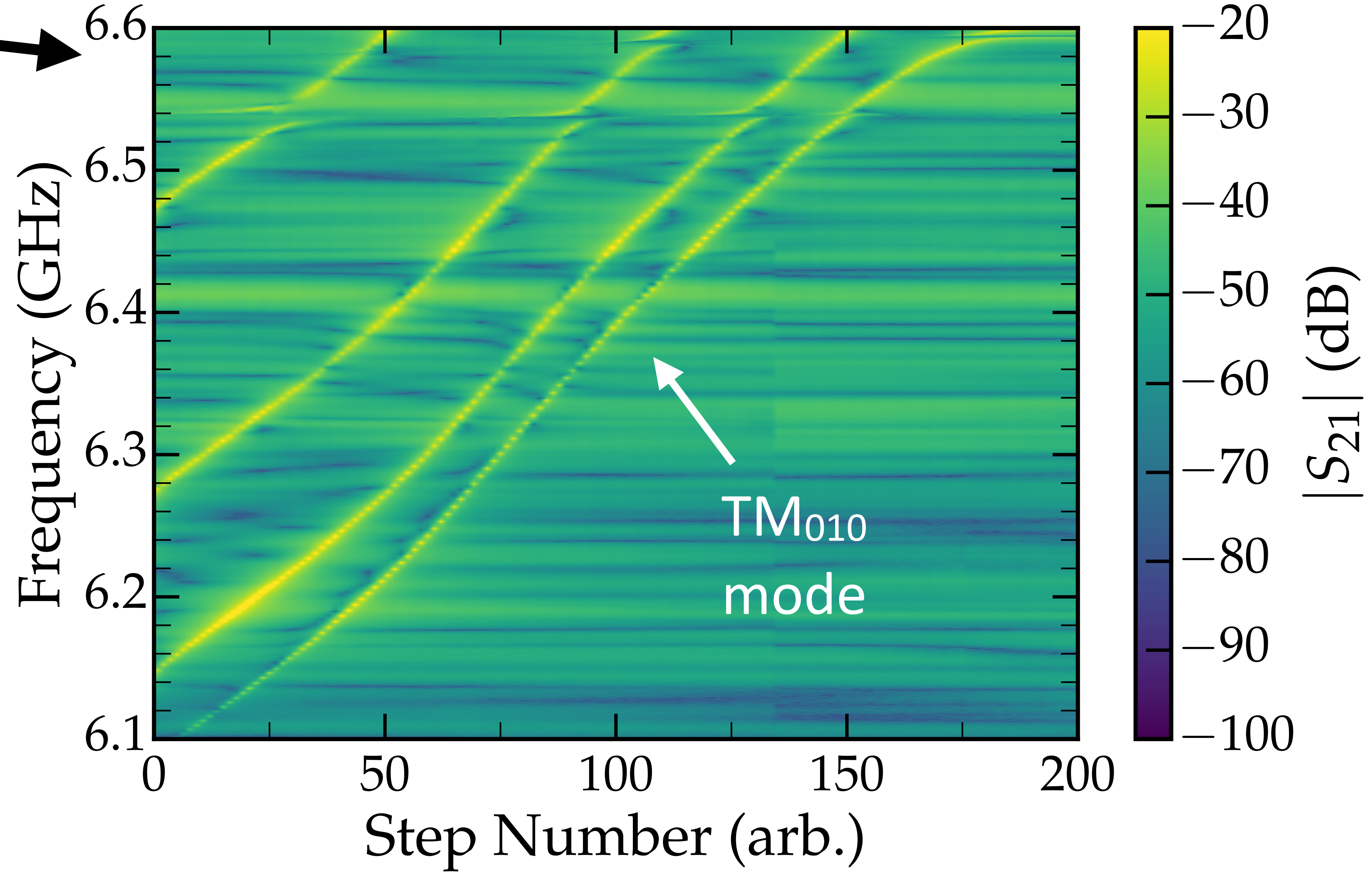

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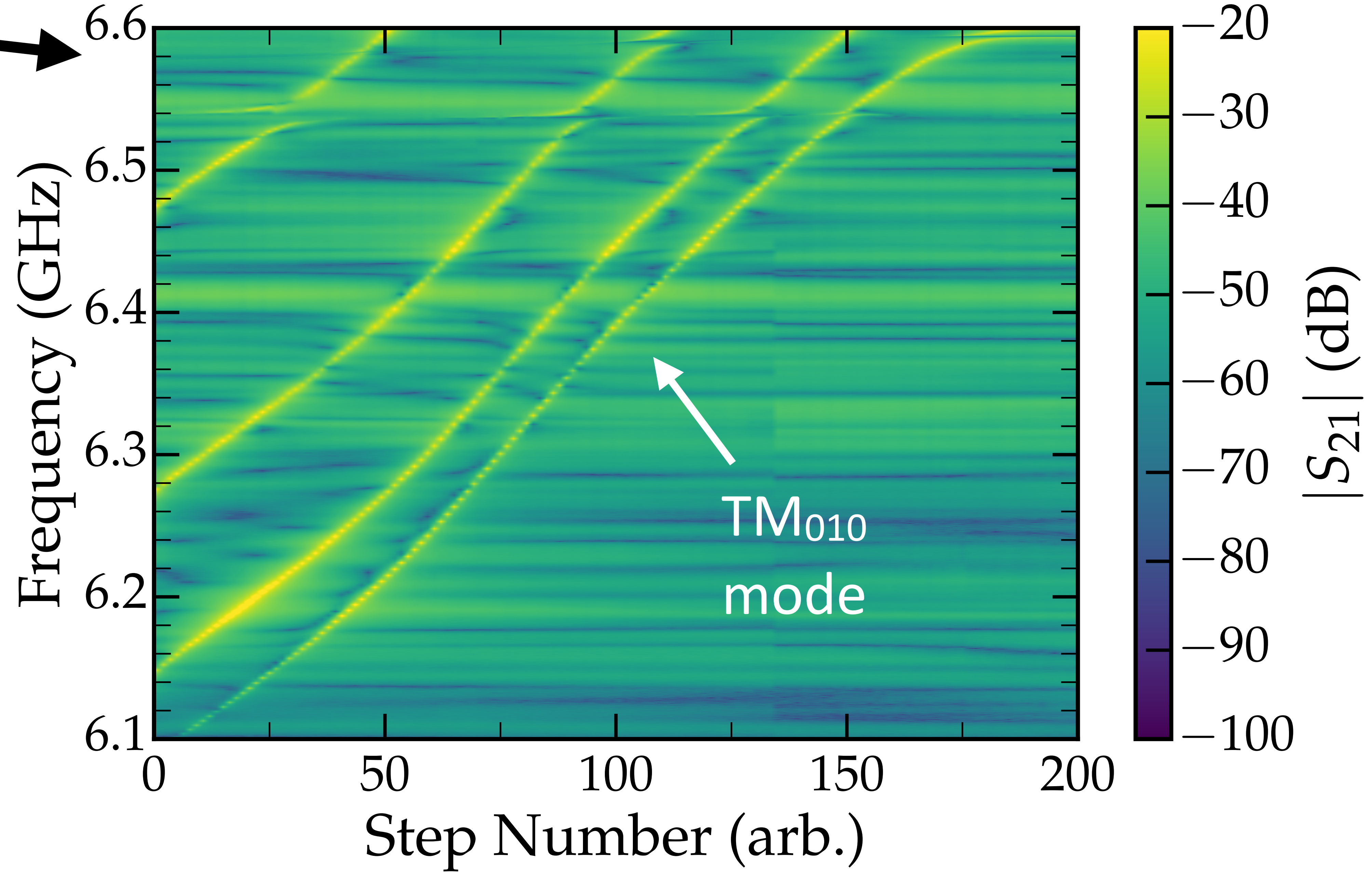

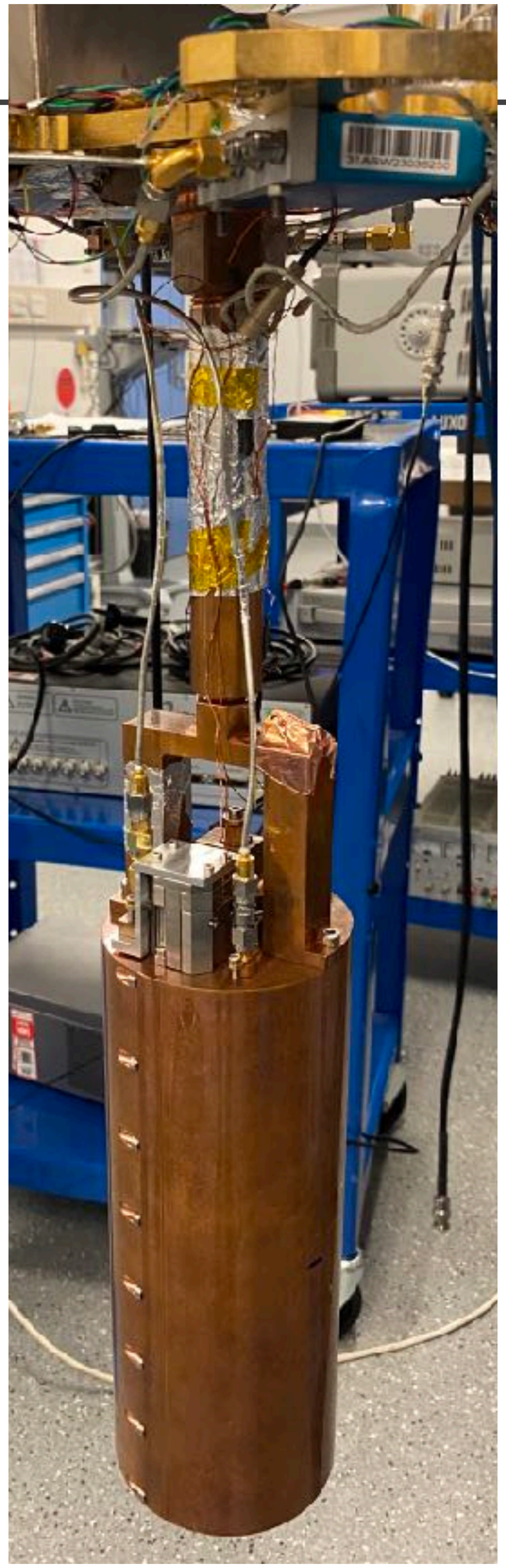

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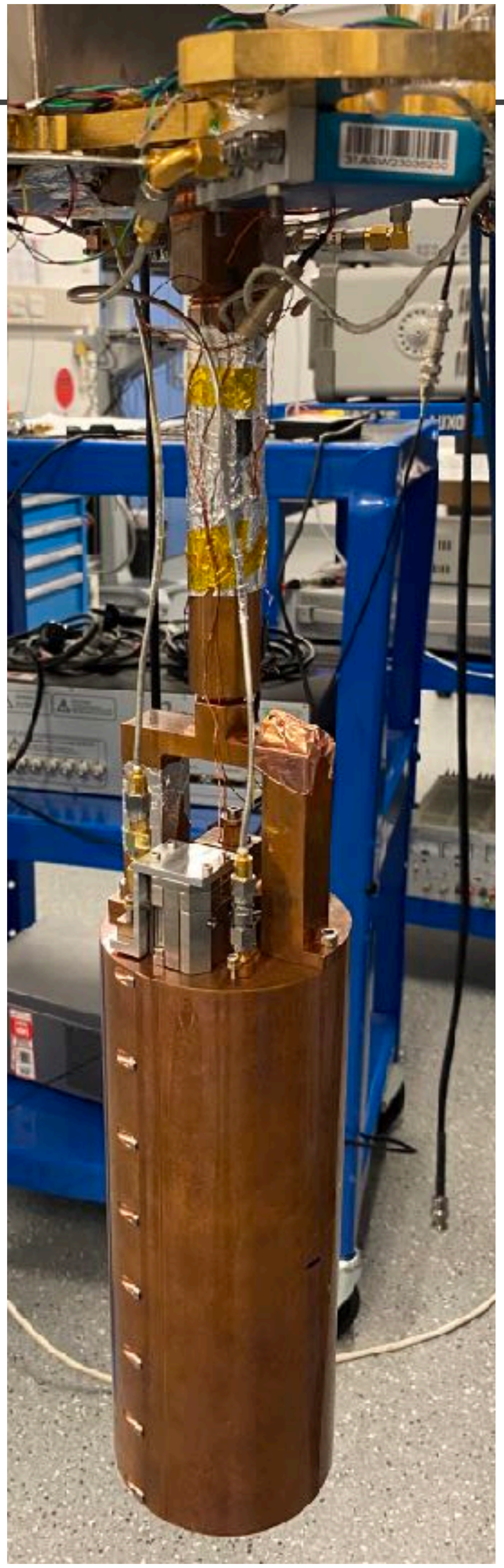

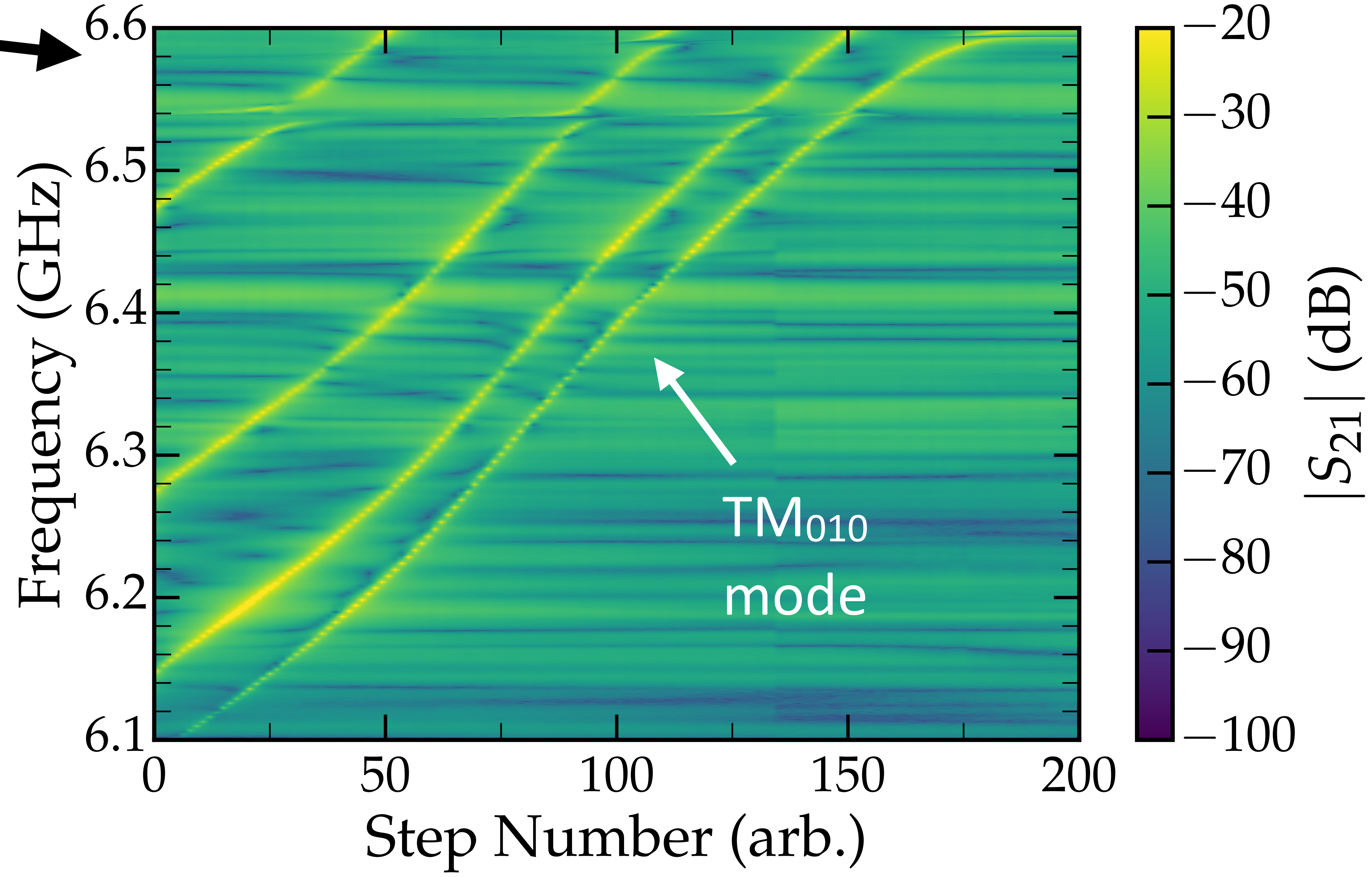

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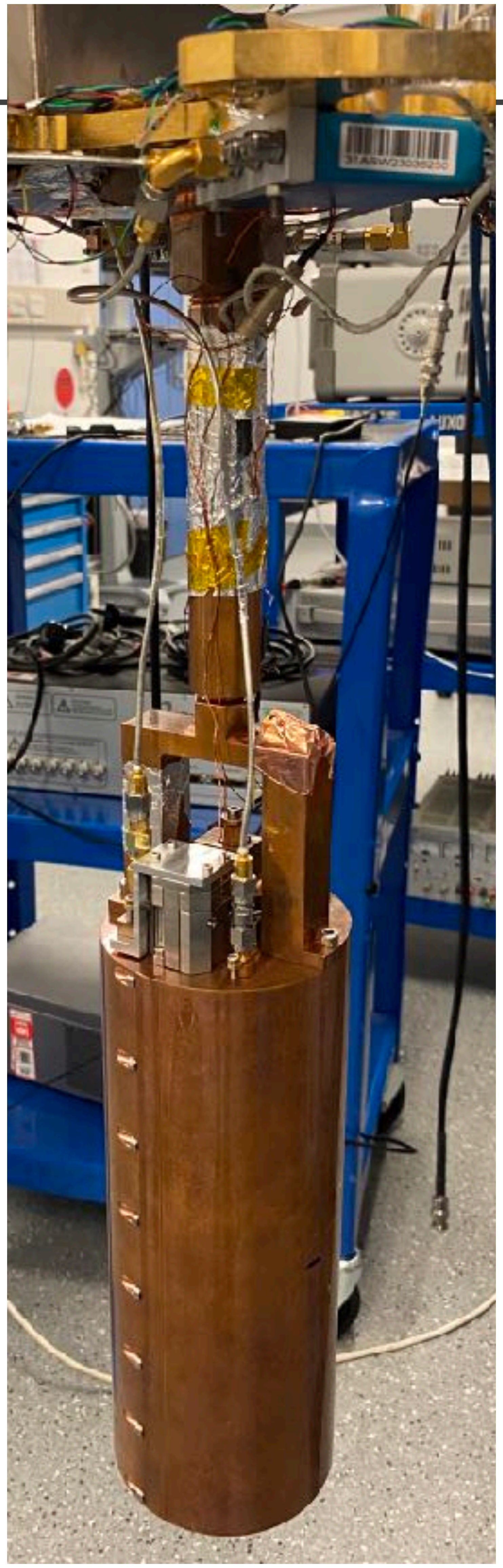
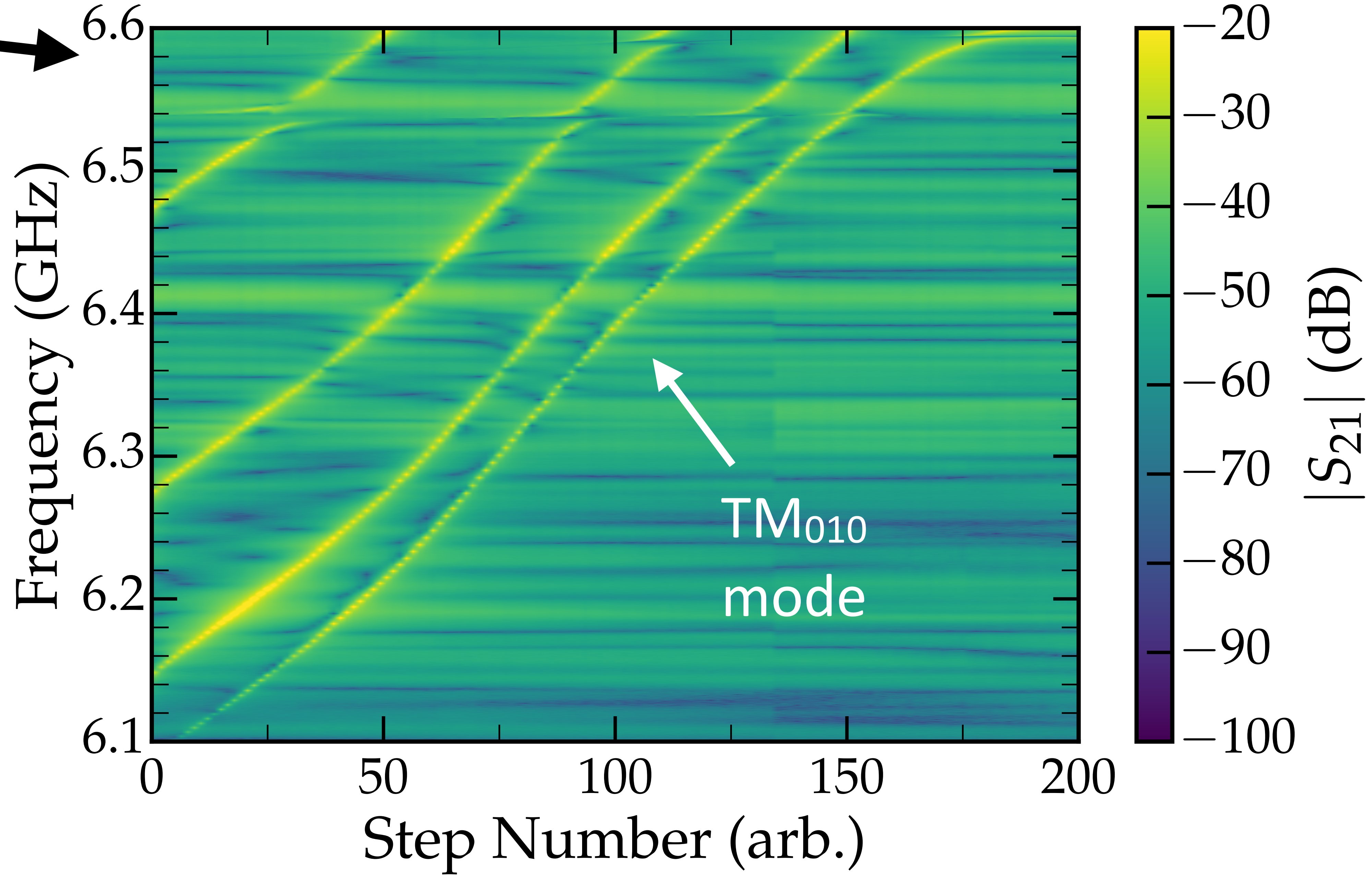
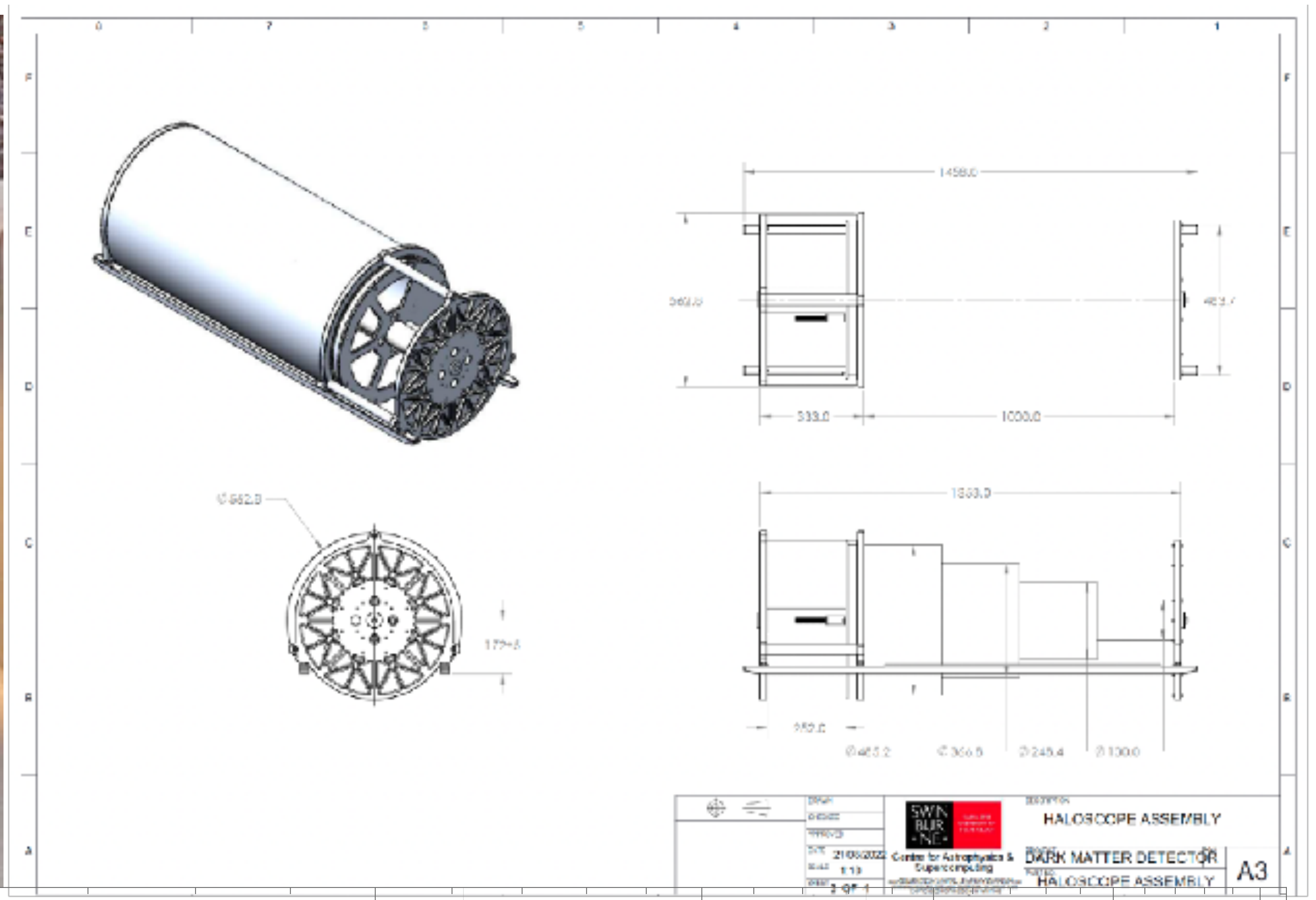
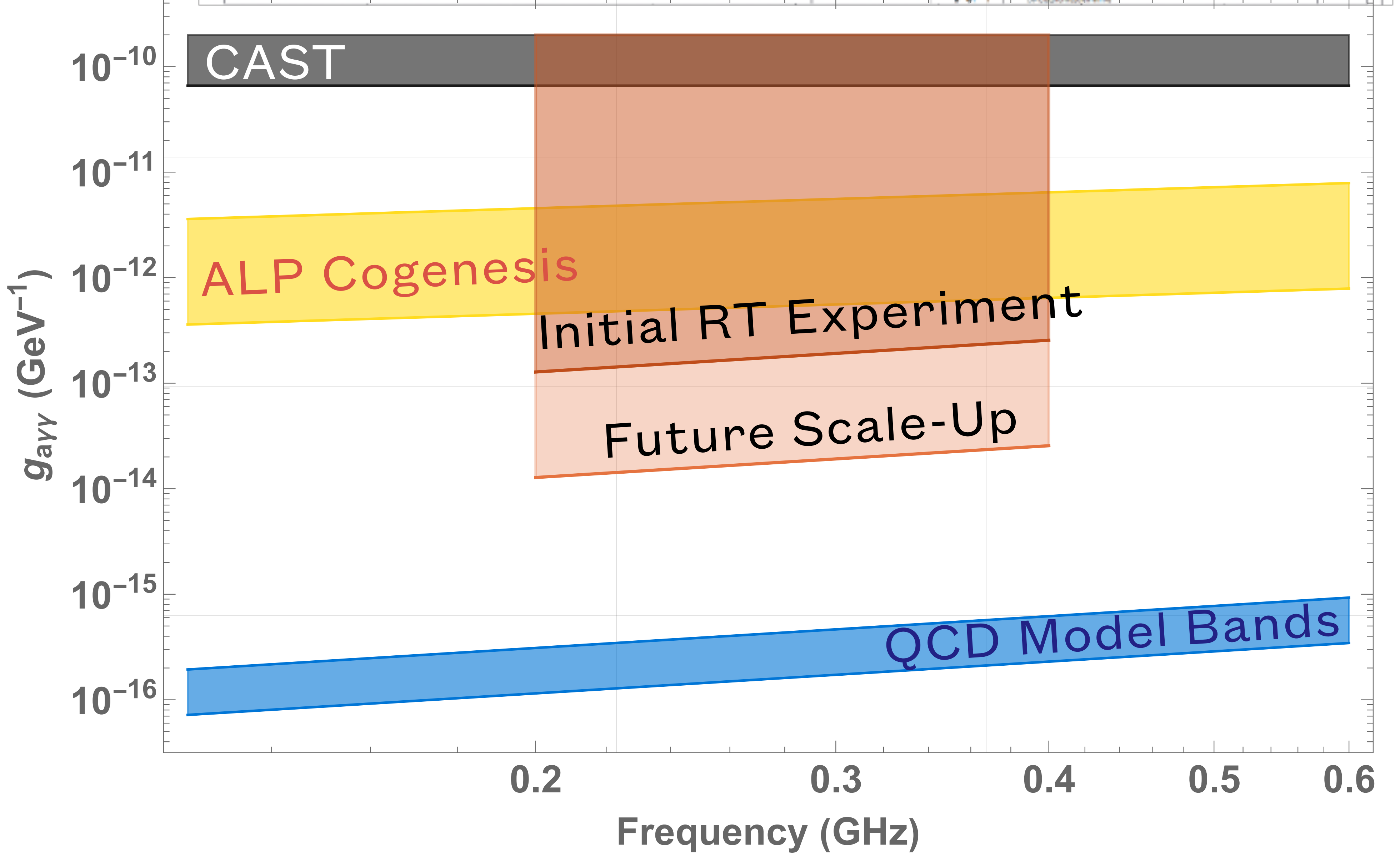




ORGAN Low Frequency

- Increased interest in low frequency axion searches (<500 MHz) in recent times
- Problem: Cavities get **HUGE**
- Can use re-entrant cavities to circumvent this issue
- “Cake-like” re-entrant cavity for deployment in large MRI magnet bore at Swinburne
- Experiment under construction





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ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

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  - Multiple cavity array: ↑V

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