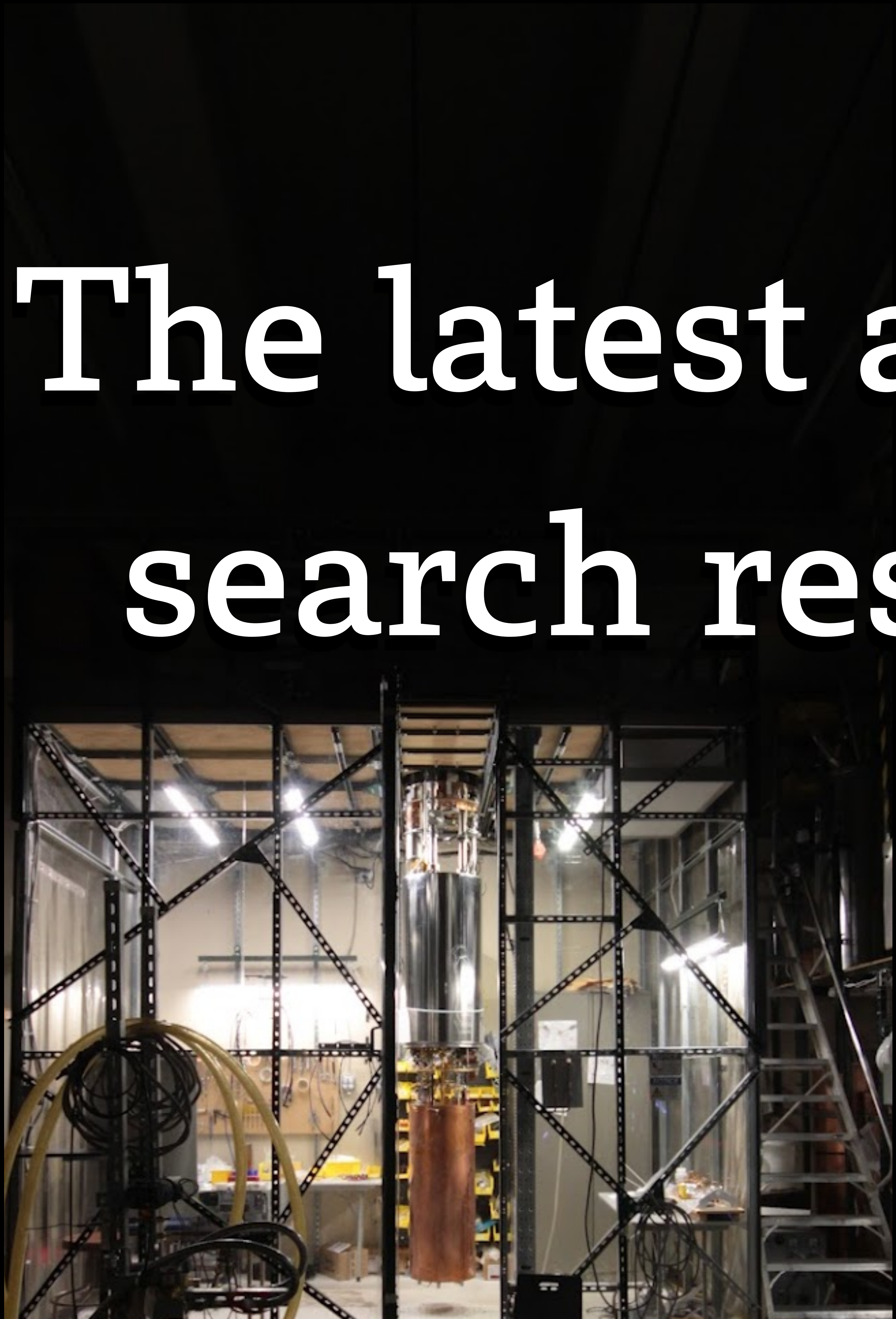
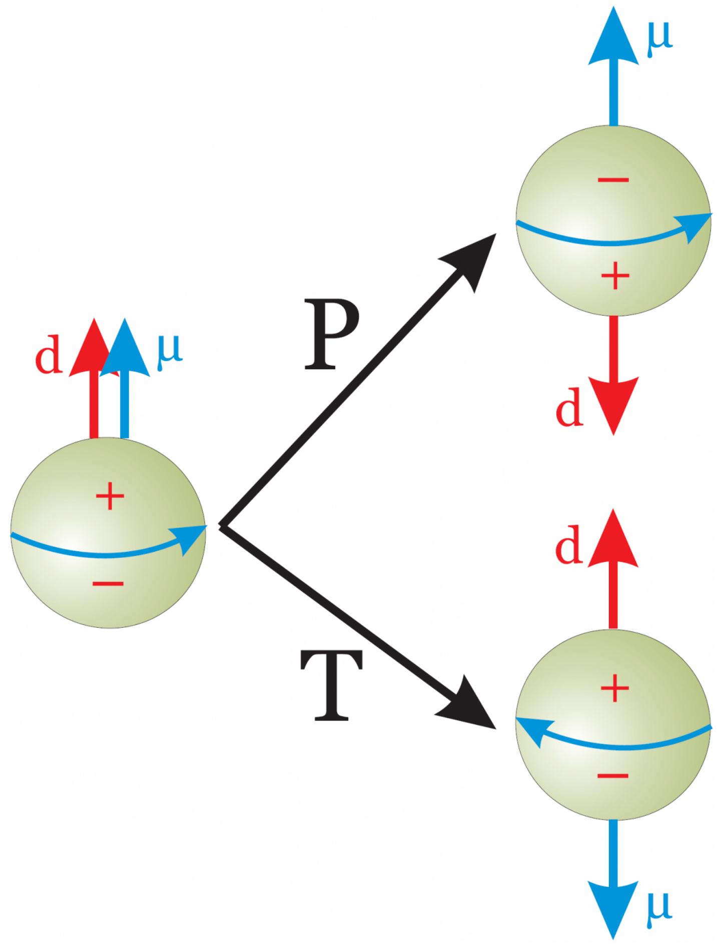
The latest axion dark matter search result with ADMX



Tatsumi Nitta (University of Washington)
@Aspen Winter Conference
March 23, 2022

Motivations

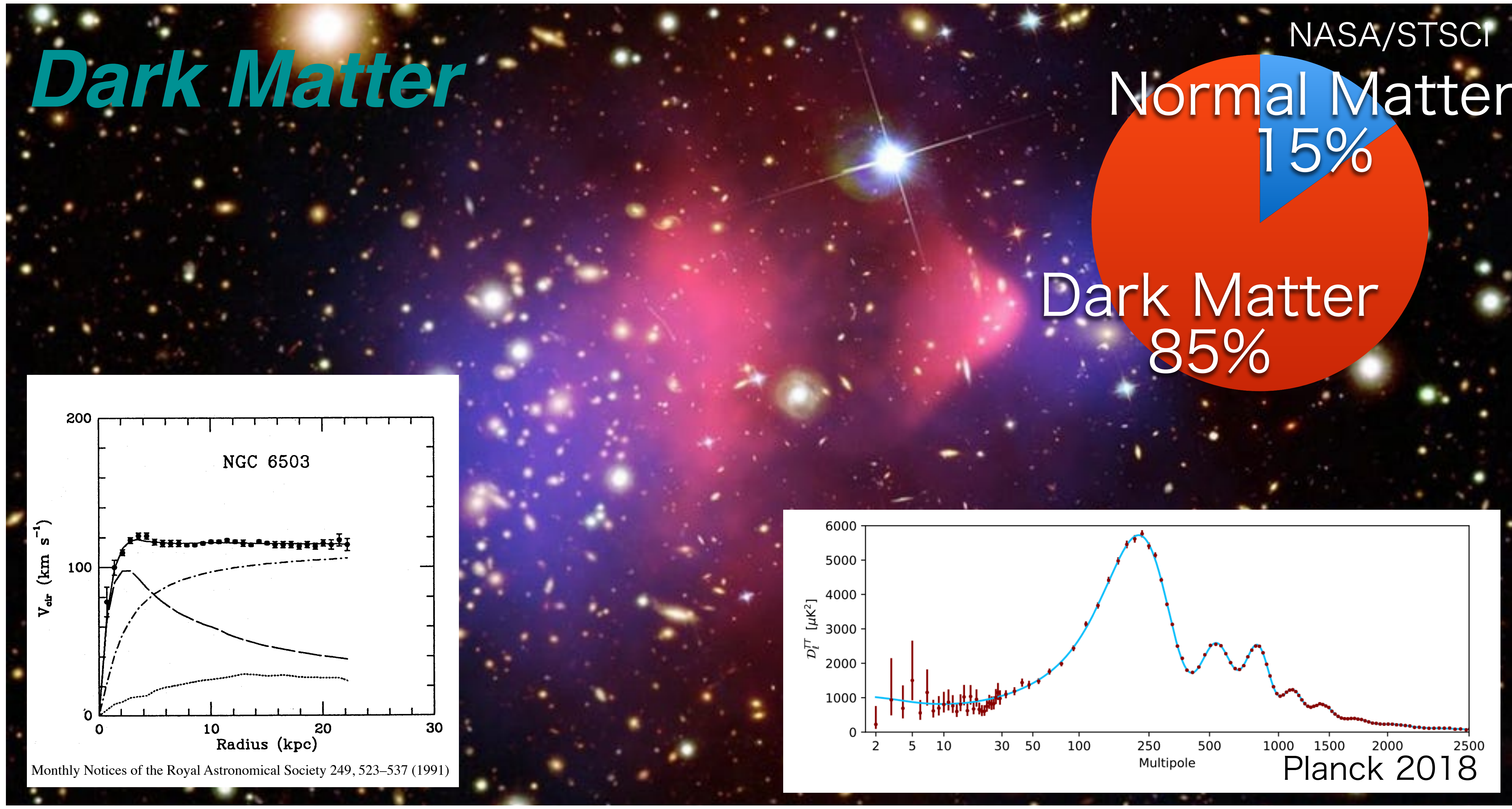


Strong CP problem

SM : $\mathcal{O}(\sim 10^{-16})\ \mathrm{e \cdot cm}$

obs. : $< 1.8 \times 10^{-26}\ \mathrm{e \cdot cm}$

(Abel et.al. \`20)

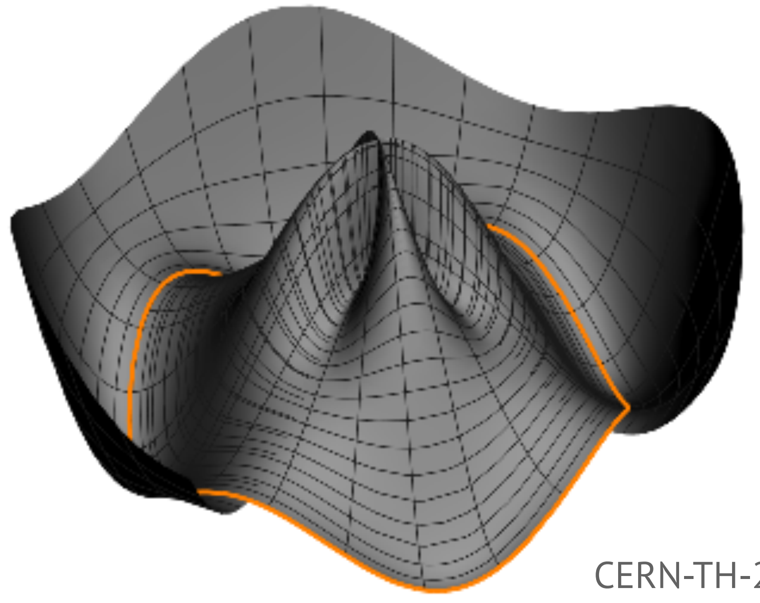


"Invisible" Axion Dark Matter

$\cancel{\mathrm{U(1)}}_{\mathrm{A}} \rightarrow \bar{\theta}_{\mathrm{QCD}} = 0$ (Peccei, Quinn \`77)

NG-boson: **axion** → **Can be DM** (Axion solution: Weinberg, Wilczek \`78 , Axion cosmology: Preskill, Wise, Wilczek, Abbott, Sikivie, Dine, Fischler, \`83)

Bench mark models: KSVZ and DFSZ, **"invisible" axion**

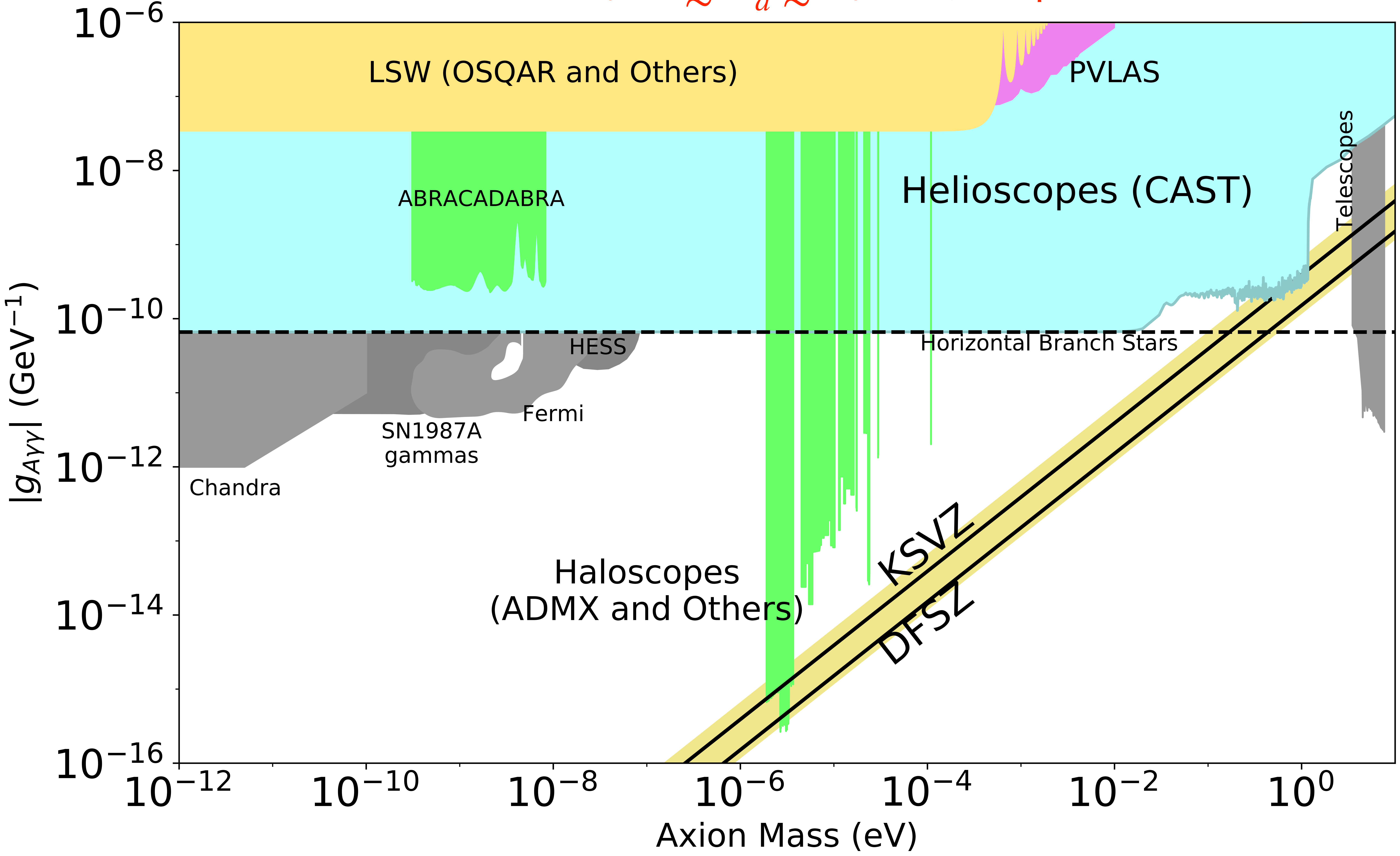


CERN-TH-2021-045

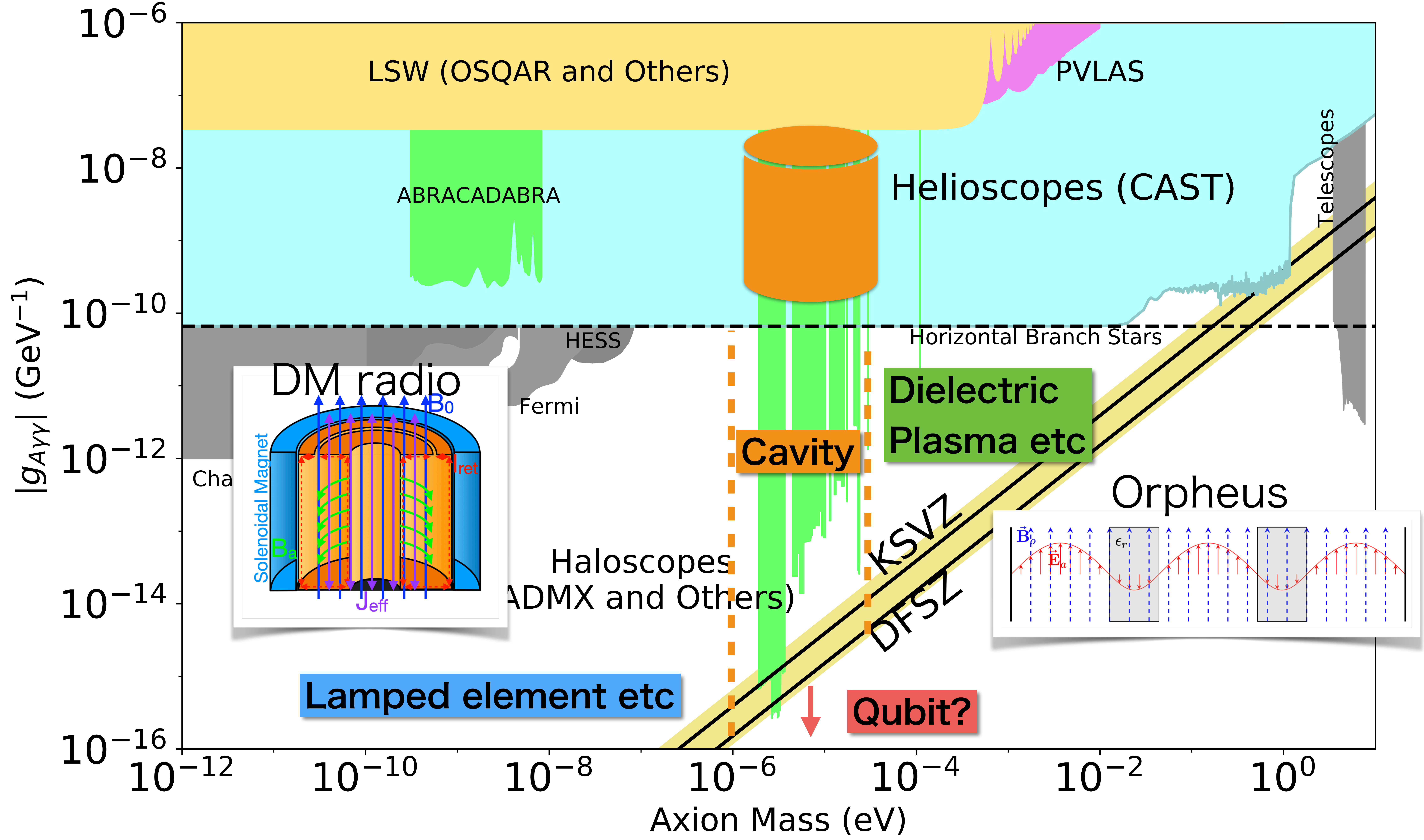
Super solid motivations and simple solution

Where to search?

cosmic structure formtion $10^{-22} \lesssim m_a \lesssim 10^{-2}$ eV supernova etc



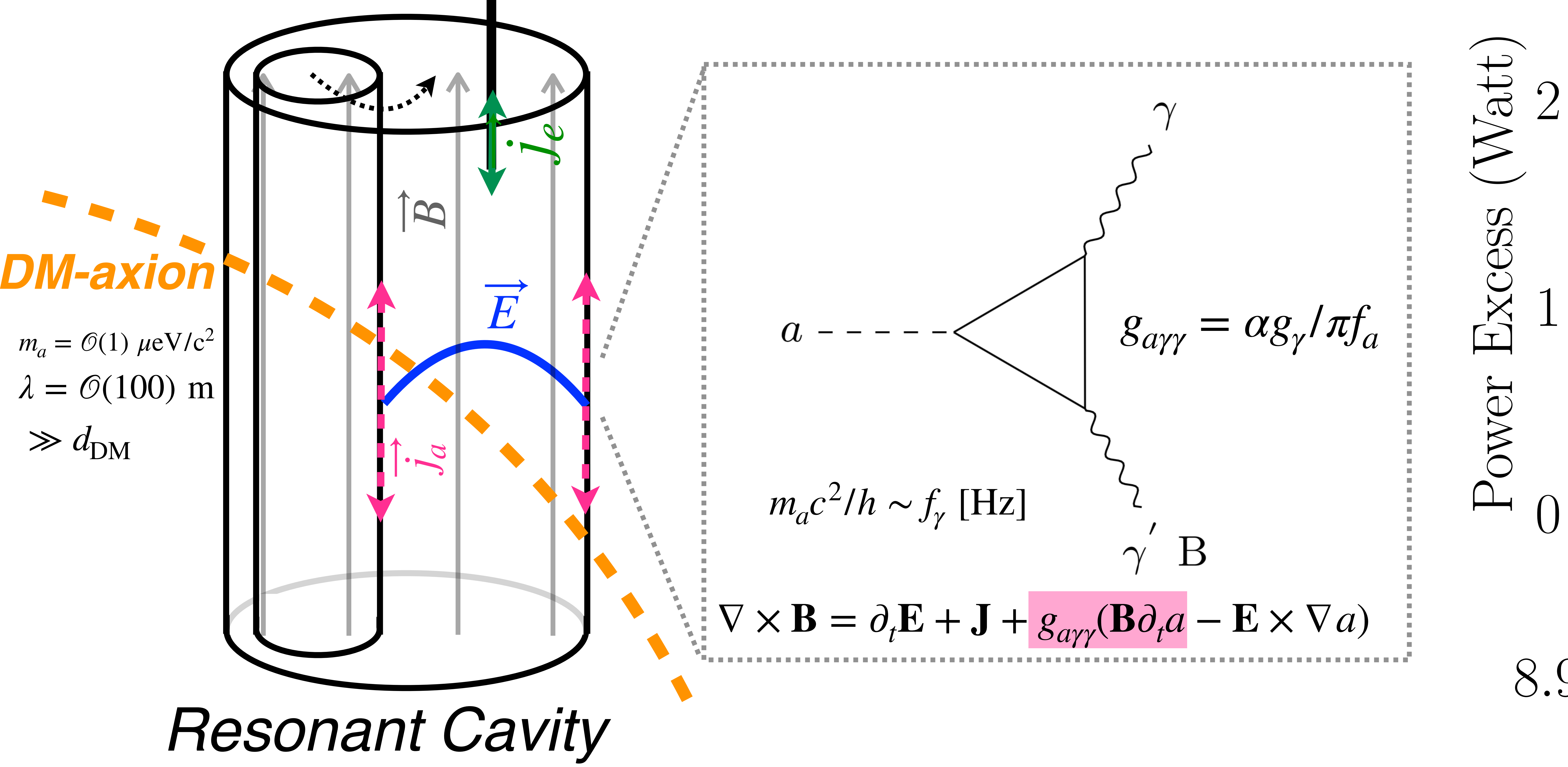
Where to search?

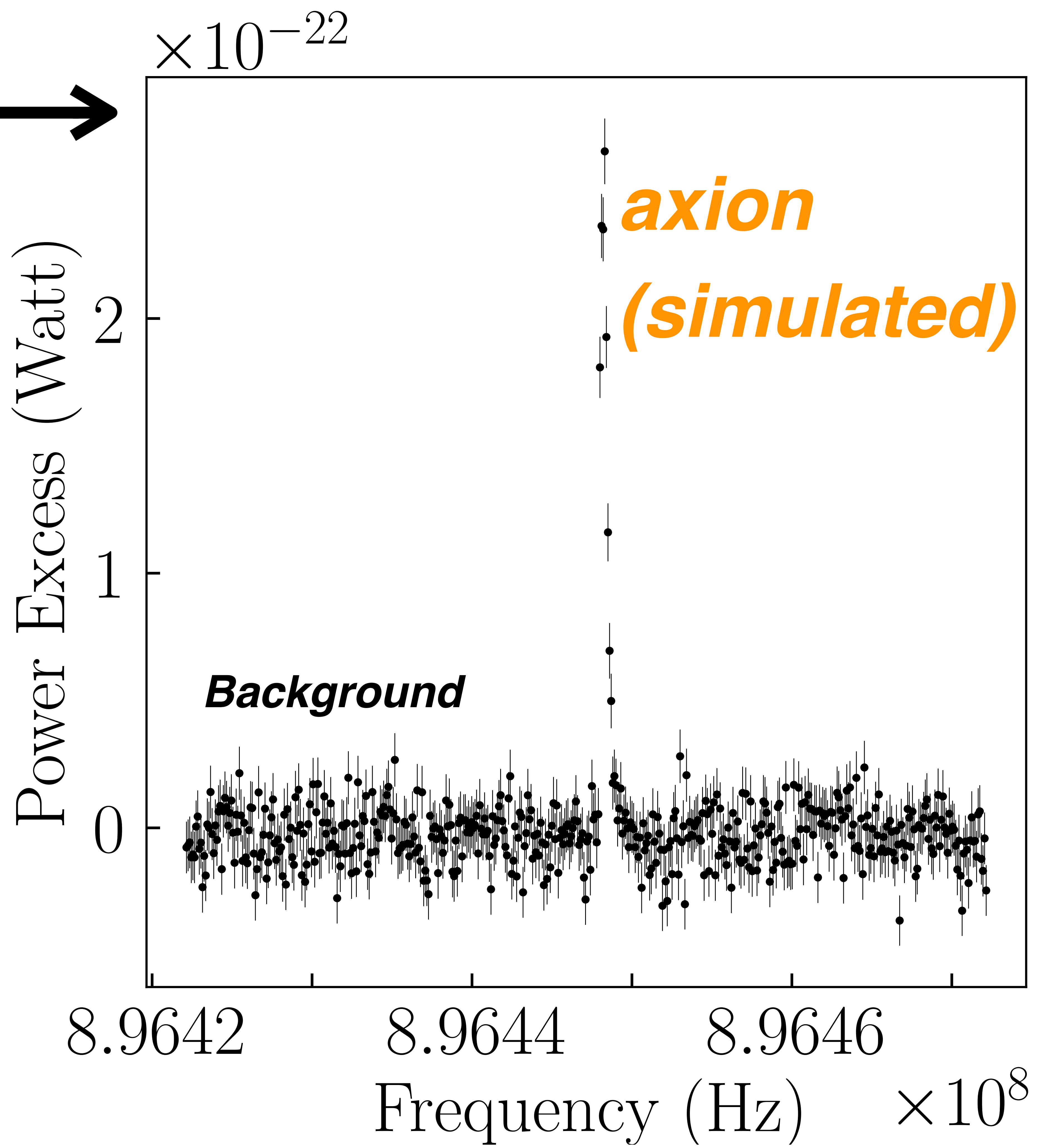


Resonant Cavity Haloscope

Only successful "invisible" axion dark matter detection technique so far

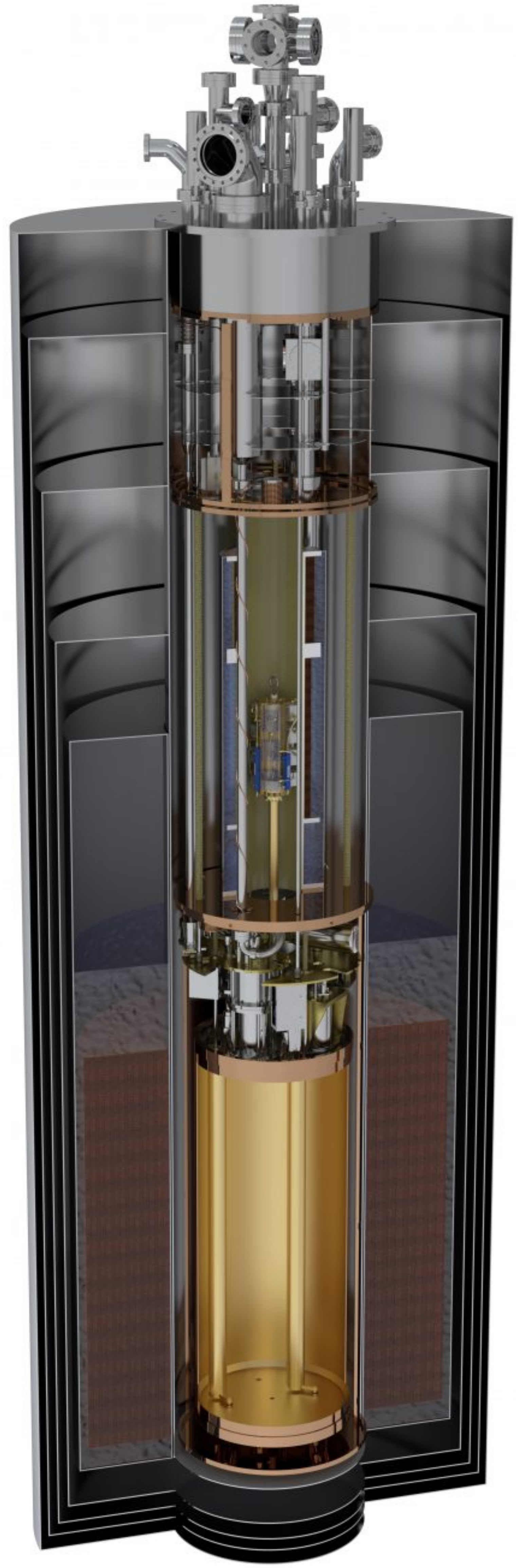
Proposed by
P. Sikivie, Phys. Rev. Lett. 51, 1415 (1983)





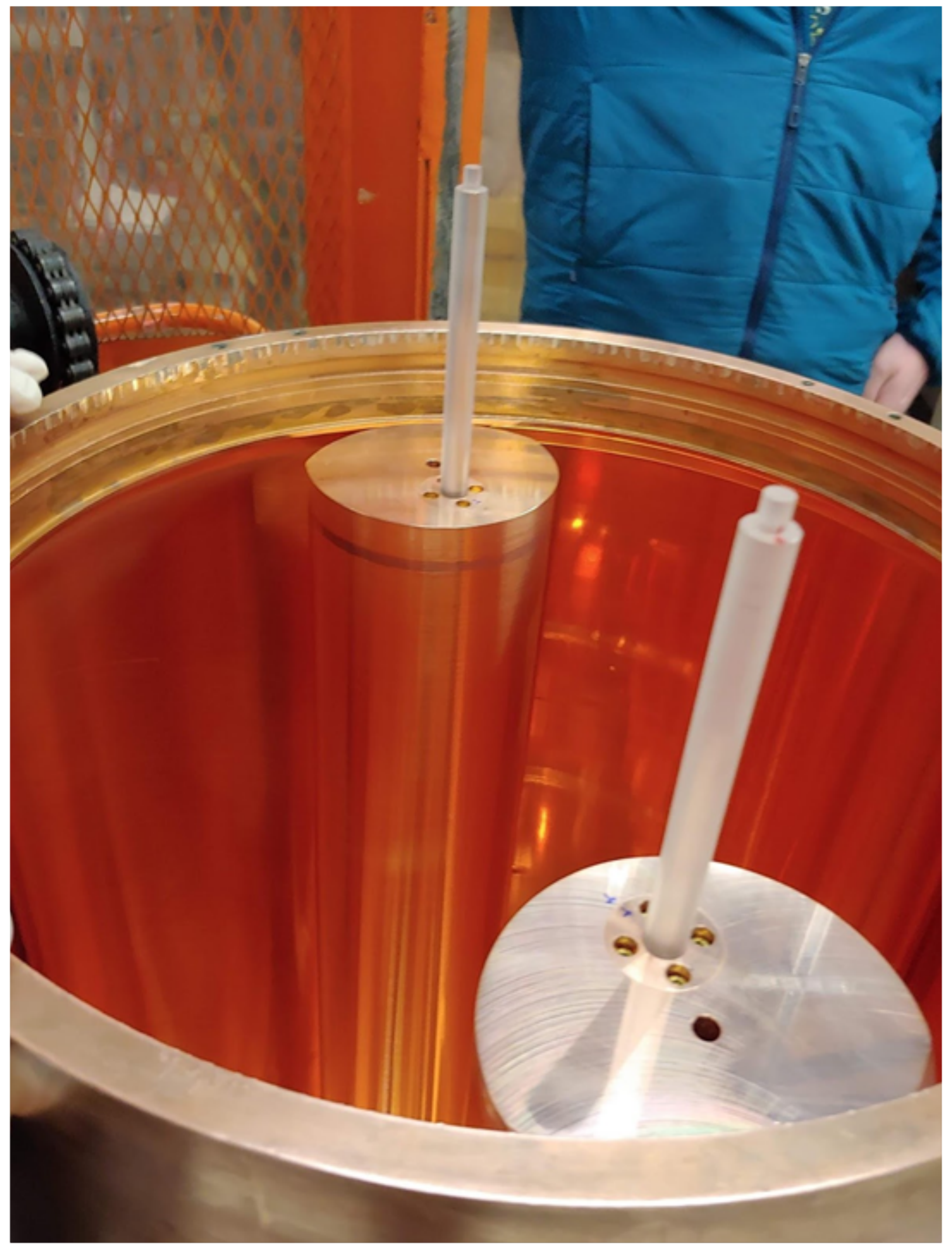
ADMX experiment

$$T_{\mathrm{sys}} = T_{\mathrm{phys}} + T_{\mathrm{amps}}$$

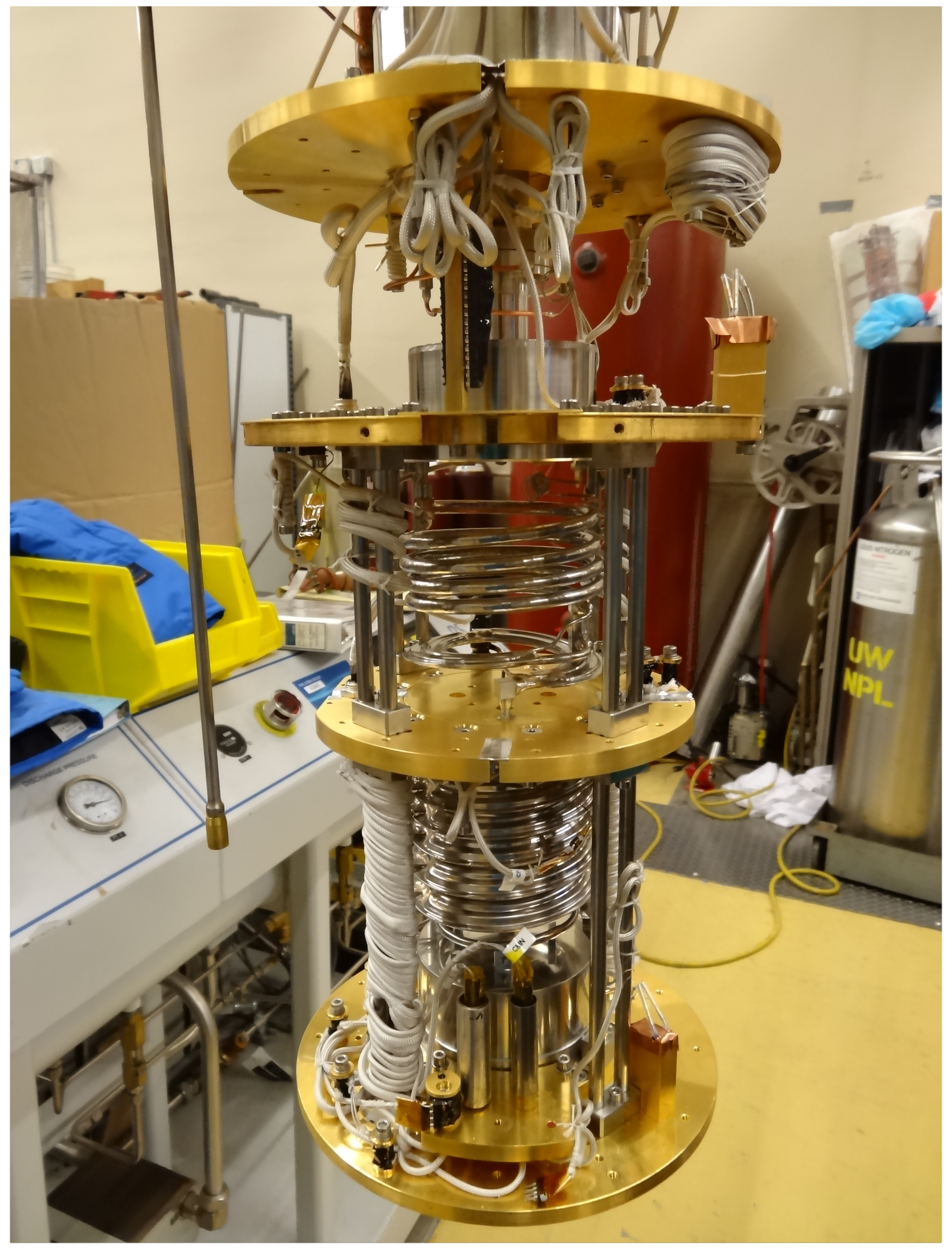


Superconducting Magnet
~ 7.6 T

High Q_L (80k)
Large V (136 L)



Dill fridge
~ 100 mK



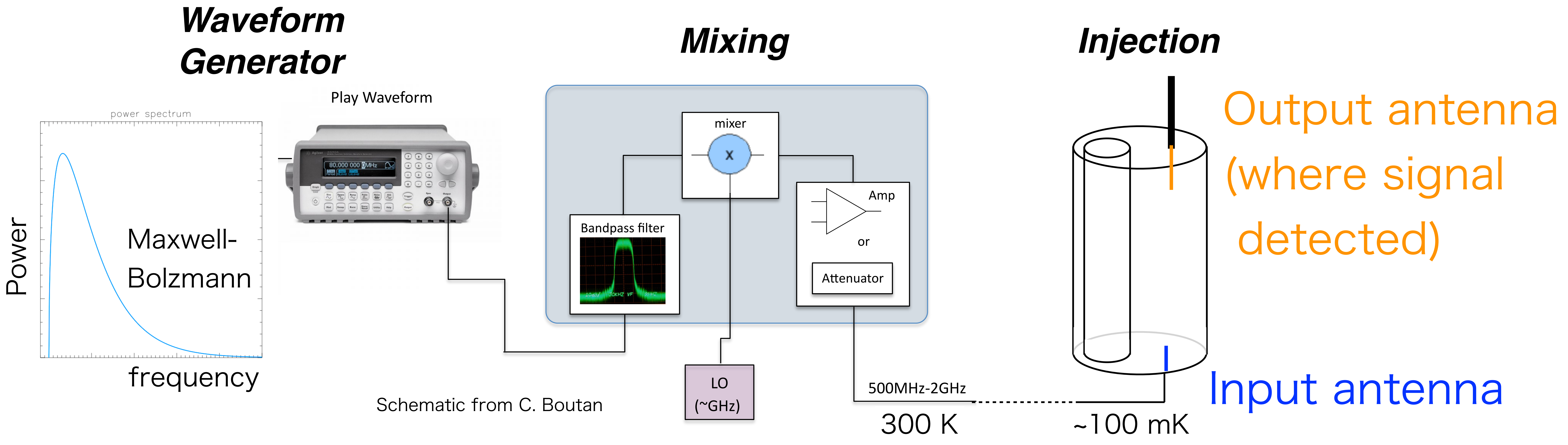
JPA ~ 100 mK
additional noise

(expected)

$$\frac{df}{dt} \propto \left(\frac{B}{7.6\ \mathrm{T}}\right)^4 \left(\frac{V}{136\ \ell}\right)^2 \left(\frac{Q_L}{80{,}000}\right) \left(\frac{0.3}{Tsys}\right)^2 \sim 500\ \mathrm{MHz/year} @ \mathrm{DFSZ}$$

Synthetic Axion Generator (SAG)

Artificial signal injection system to test RF system and analyzers



Schematic from C. Boutan

Our results

2018: First DFSZ limit 2.7-2.8 μeV

PHYSICAL REVIEW LETTERS **120,** 151301 (2018)

Editors' Suggestion | Featured in Physics

Search for Invisible Axion Dark Matter with the Axion Dark Matter Experiment

N. Du,[1] N. Force,[1] R. Khatiwada,[1] E. Lentz,[1] R. Ottens,[1] L. J Rosenberg,[1] G. Rybka,[1,*] G. Carosi,[2] N. Woollett,[2] D. Bowring,[3] A. S. Chou,[3] A. Sonnenschein,[3] W. Wester,[3] C. Boutan,[4] N. S. Oblath,[4] R. Bradley,[5] E. J. Daw,[6] A. V. Dixit,[7] J. Clarke,[8] S. R. O'Kelley,[8] N. Crisosto,[9] J. R. Gleason,[9] S. Jois,[9] P. Sikivie,[9] I. Stern,[9] N. S. Sullivan,[9] D. B Tanner,[9]

(ADMX Collaboration) and G. C. Hilton[10]

2020: Extended to 2.8-3.3 μeV

PHYSICAL REVIEW LETTERS **124,** 101303 (2020)

Editors' Suggestion

Extended Search for the Invisible Axion with the Axion Dark Matter Experiment

T. Braine,[1] R. Cervantes,[1] N. Crisosto,[1] N. Du,[1,*] S. Kimes,[1] L. J. Rosenberg,[1] G. Rybka,[1] J. Yang,[1] D. Bowring,[2] A. S. Chou,[2] R. Khatiwada,[2] A. Sonnenschein,[2] W. Wester,[2] G. Carosi,[3] N. Woollett,[3] L. D. Duffy,[4] R. Bradley,[5] C. Boutan,[6] M. Jones,[6] B. H. LaRoque,[6] N. S. Oblath,[6] M. S. Taubman,[6] J. Clarke,[7] A. Dove,[7] A. Eddins,[7] S. R. O'Kelley,[7] S. Nawaz,[7] I. Siddiqi,[7] N. Stevenson,[7] A. Agrawal,[8] A. V. Dixit,[8] J. R. Gleason,[9] S. Jois,[9] P. Sikivie,[9] J. A. Solomon,[9] N. S. Sullivan,[9] D. B. Tanner,[9] E. Lentz,[10] E. J. Daw,[11] J. H. Buckley,[12] P. M. Harrington,[12] E. A. Henriksen,[12] and K. W. Murch[12]

(ADMX Collaboration)

2021: This talk (published from PRL)

https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.127.261803

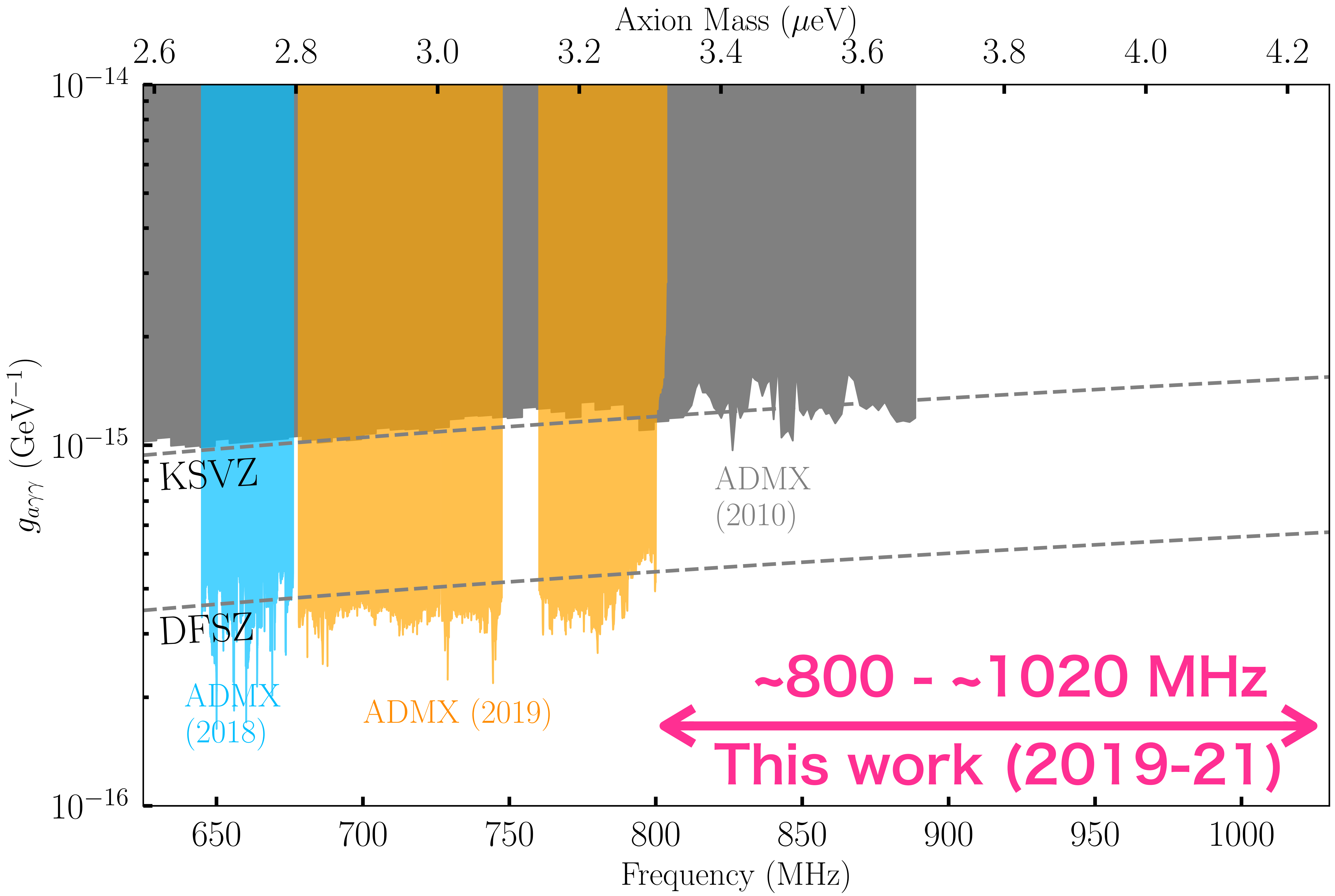
PHYSICAL REVIEW LETTERS **127,** 261803 (2021)

Editors' Suggestion | Featured in Physics

Search for Invisible Axion Dark Matter in the 3.3–4.2 μeV Mass Range

C. Bartram,[1] T. Braine,[1] E. Burns,[1] R. Cervantes,[1] N. Crisosto,[1] N. Du,[1] H. Korandla,[1] G. Leum,[1] P. Mohapatra,[1] T. Nitta,[1,*] L. J Rosenberg,[1] G. Rybka,[1] J. Yang,[1] John Clarke,[2] I. Siddiqi,[2] A. Agrawal,[3] A. V. Dixit,[3] M. H. Awida,[4] A. S. Chou,[4] M. Hollister,[4] S. Knirck,[4] A. Sonnenschein,[4] W. Wester,[4] J. R. Gleason,[5] A. T. Hipp,[5] S. Jois,[5] P. Sikivie,[5] N. S. Sullivan,[5] D. B. Tanner,[5] E. Lentz,[6] R. Khatiwada,[7,4] G. Carosi,[8] N. Robertson,[8] N. Woollett,[8] L. D. Duffy,[9] C. Boutan,[10] M. Jones,[10] B. H. LaRoque,[10] N. S. Oblath,[10] M. S. Taubman,[10] E. J. Daw,[11] M. G. Perry,[11] J. H. Buckley,[12] C. Gaikwad,[12] J. Hoffman,[12] K. W. Murch,[12] M. Goryachev,[13] B. T. McAllister,[13] A. Quiskamp,[13] C. Thomson,[13] and M. E. Tobar[13]

Data-taking Summary



Period:

October 2019 - May 2021

Frequency range:

~800 - ~1020 MHz

→ **The widest coverage** (for DFSZ)

Noise Temperature:

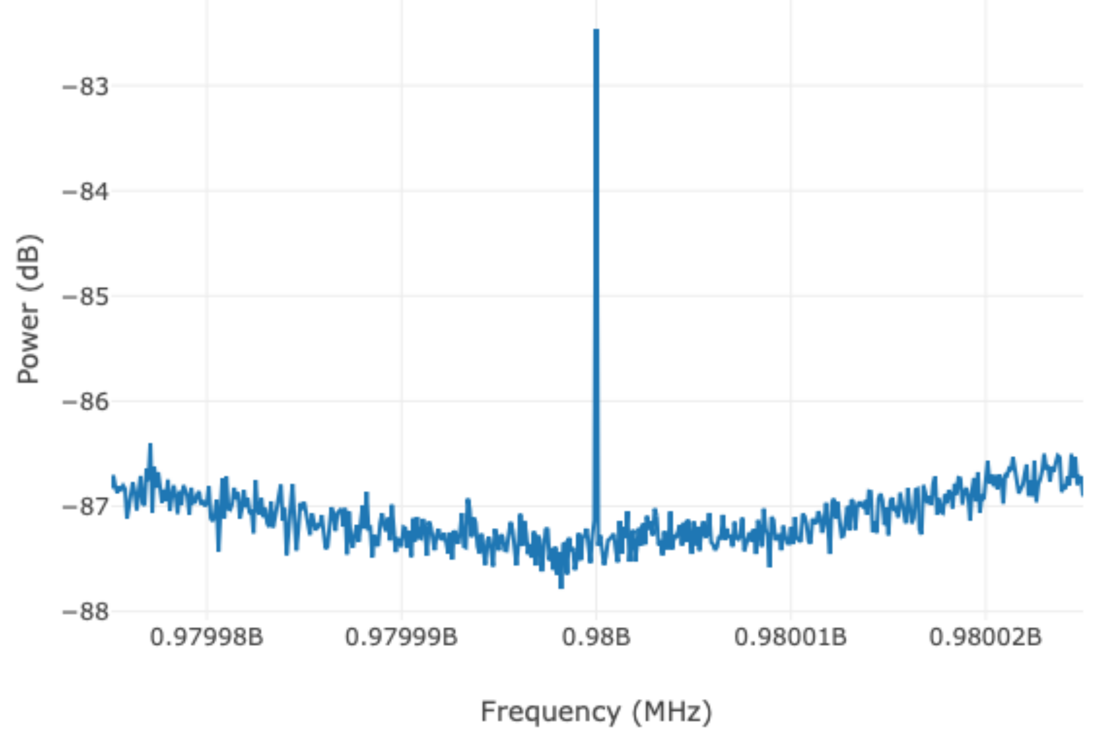
Measured with SNRI and y-factor measurements

→ **~600 mK (expected: ~300 mK)**

Observed Excesses

Found 15 excesses in 800-1020 MHz

Frequency [MHz]	Persistence	At Same Frequency	Not in Air	Enhanced on Resonance
839.669	✓	×	✓	×
840.268	✓	✓	✓	×
860.000	✓	✓	×	×
891.070	✓	✓	✓	×
896.448	✓	✓	✓	✓
974.989	×	✓	✓	×
974.999	×	✓	✓	×
960.000	✓	✓	×	×
980.000	✓	✓	×	×
990.000	✓	✓	×	×
990.031	×	✓	✓	×
1000.000	✓	✓	×	×
1000.013	×	✓	✓	×
1010.000	✓	✓	×	×
1020.000	✓	✓	×	×



14 excesses were identified as non-axion-like excesses right away.

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980.000				×
990.000				×
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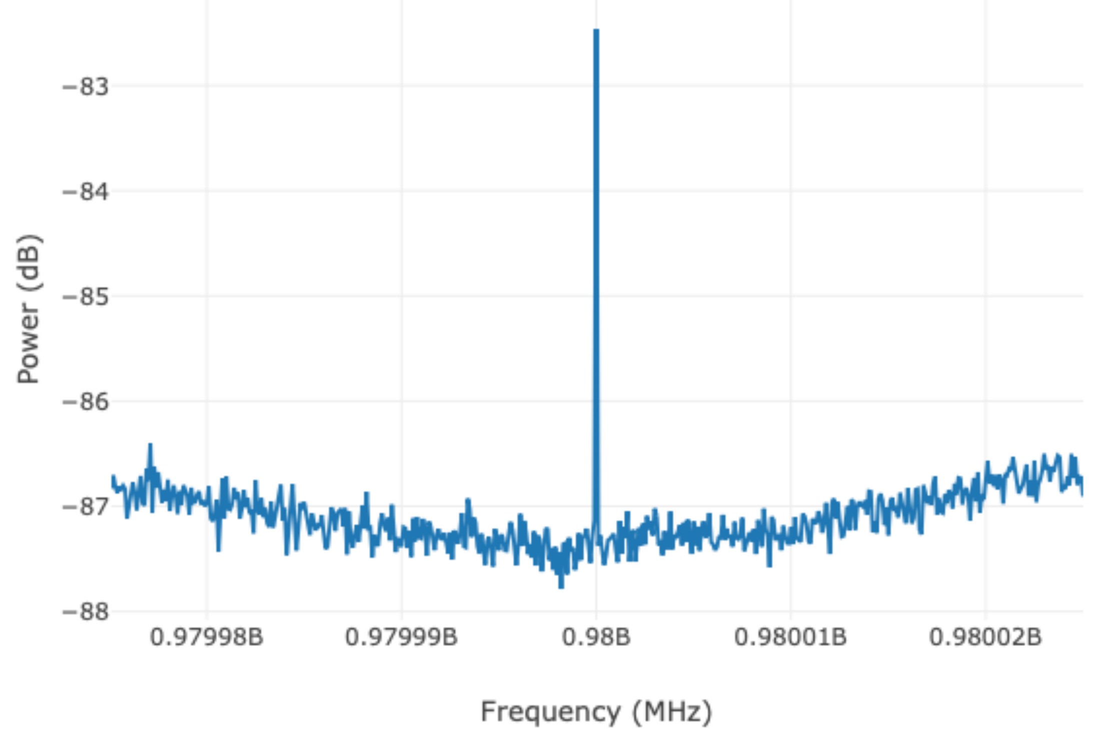
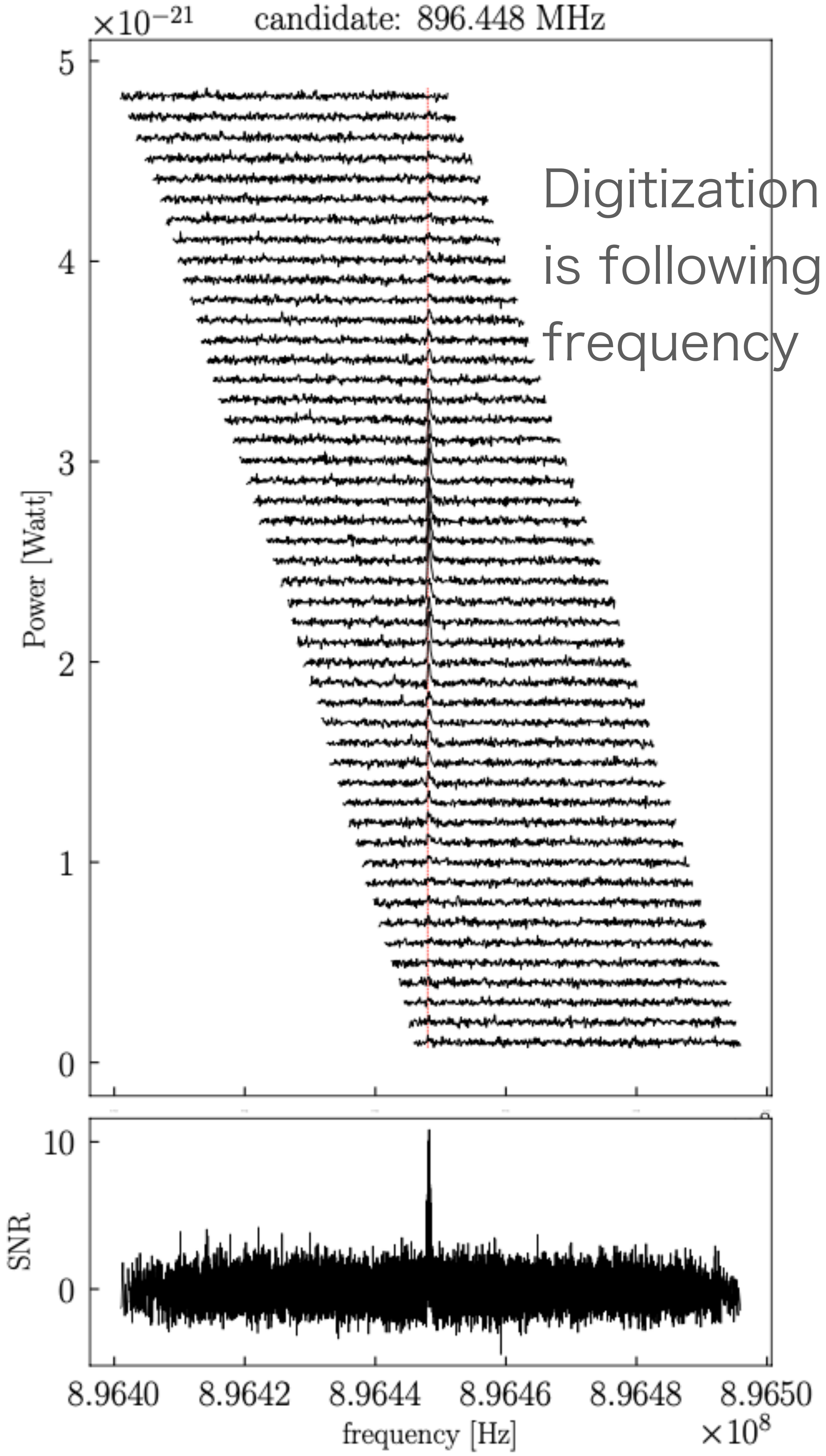
1000.000	✓	✓	×	×
1000.013	×	✓	✓	×
1010.000	✓	✓	×	×
1020.000	✓	✓	×	×

896.448 MHz is really axion-like!



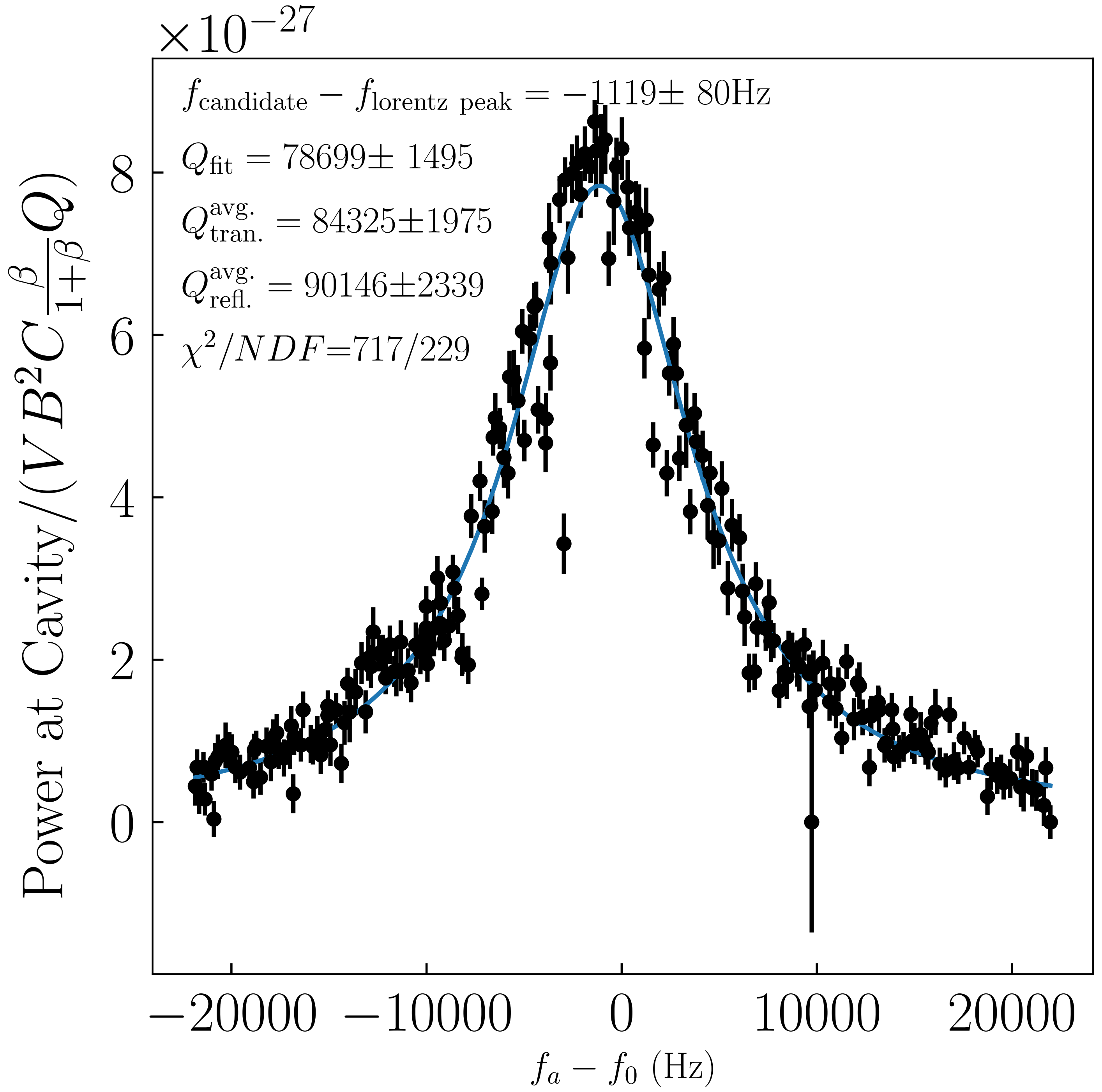
14 excesses were identified as non-axion-like excesses right away.

Stringent Axion Tests



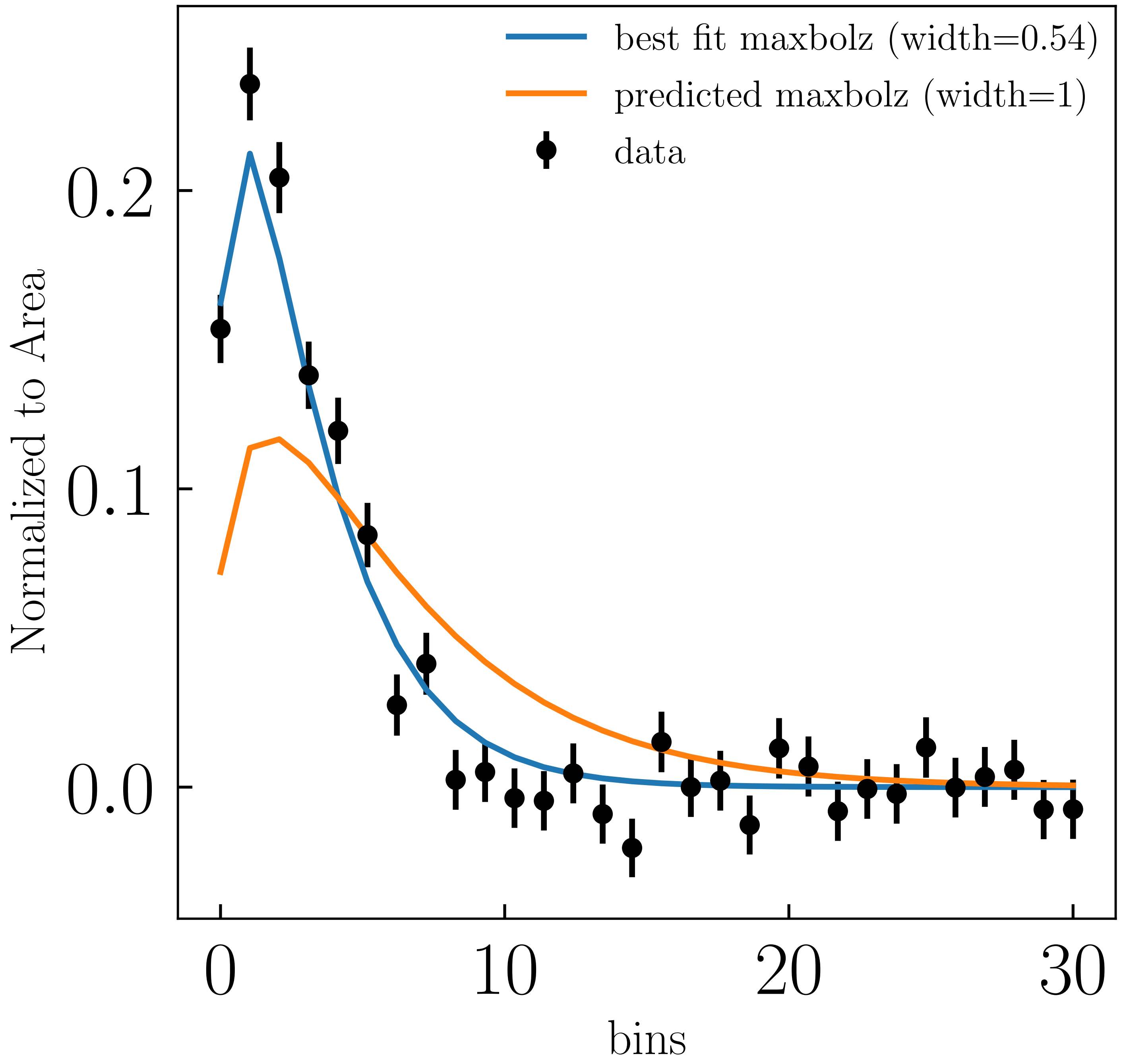
Digitization window is following resonant frequency

←*Test1: Persistance*



Test2: Cavity Enhancement

Axion is enhanced by cavity Lorentzian shape.

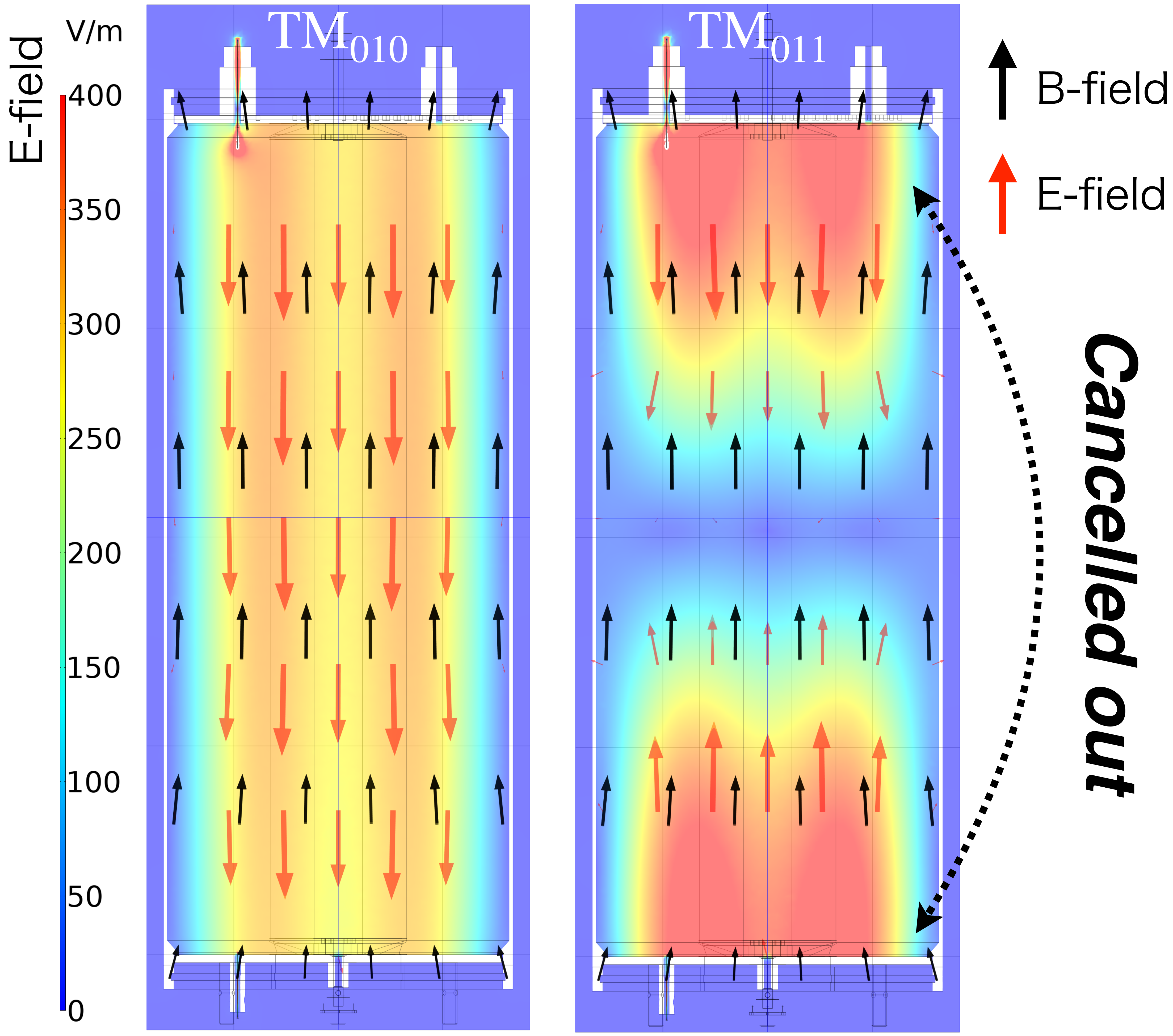


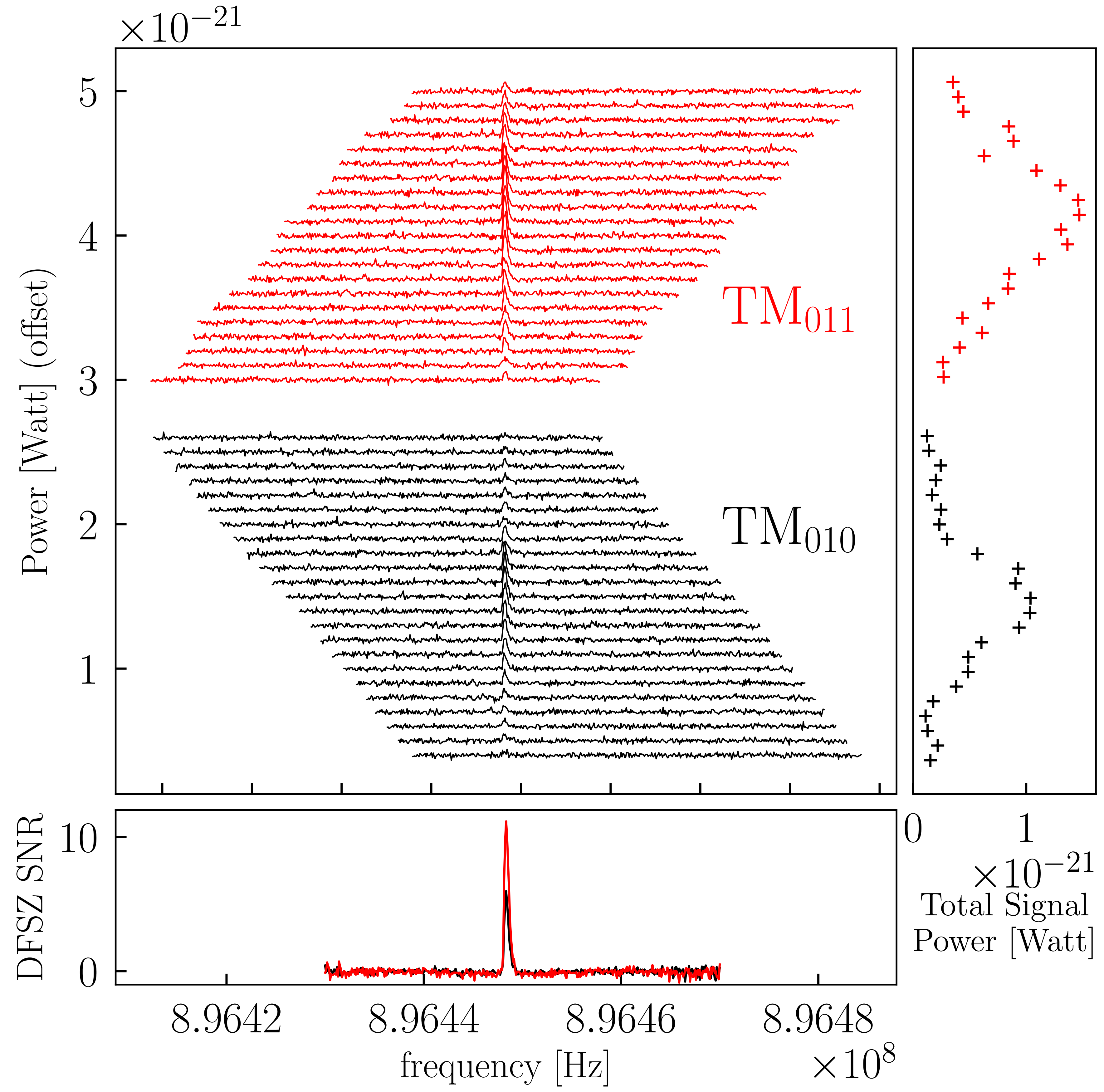
Test3: Signal Shape

Axion is expected to be maxwell-boltzman distribution

Stringent Axion Tests

Test4: Disappearance in TM011





It turns out to be blinded synthetic signal (not axion).

→ We verify our procedure to detect axions

Results

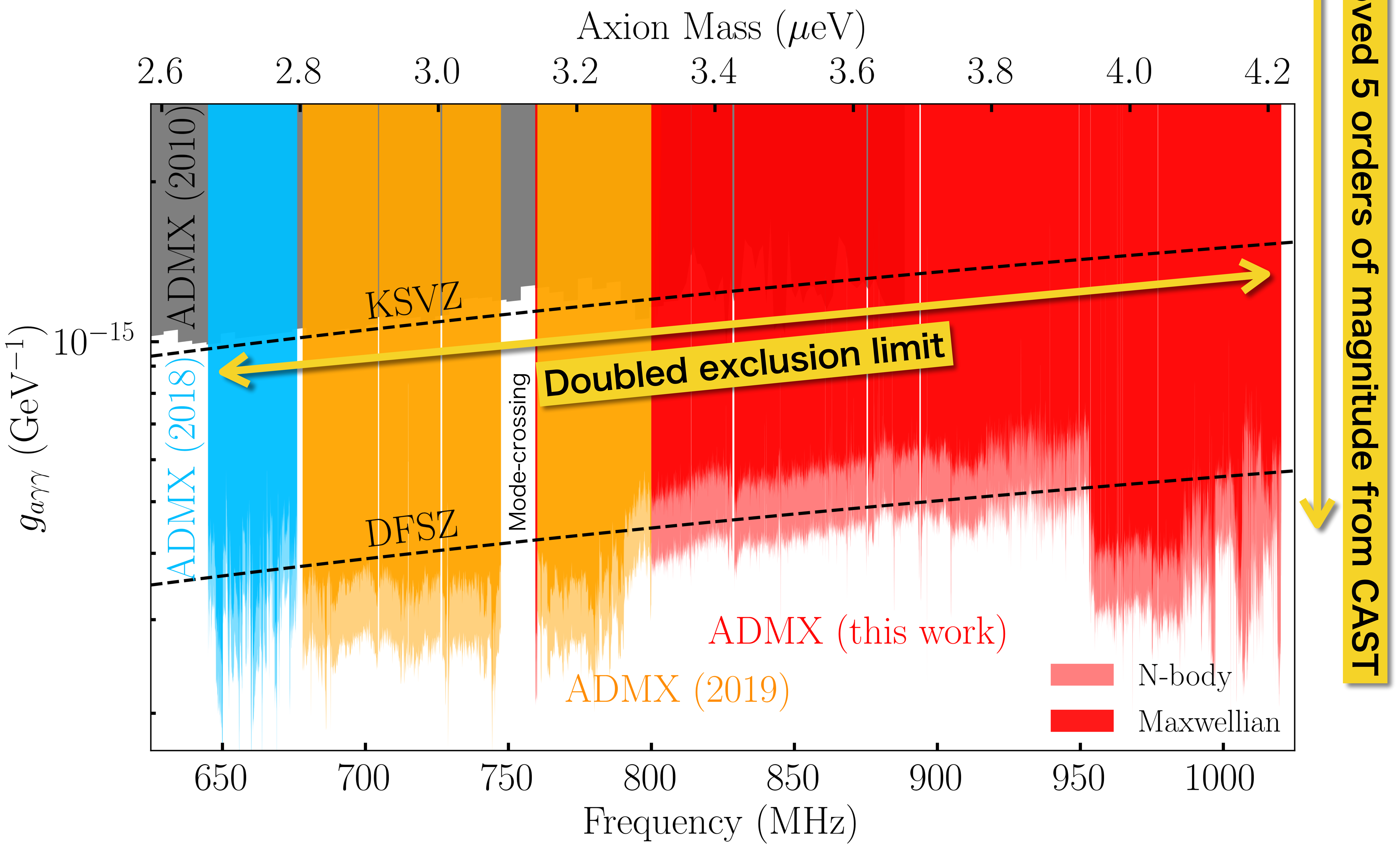
Ruled out:

KSVZ axions

800 – 1020 MHz

DFSZ axions

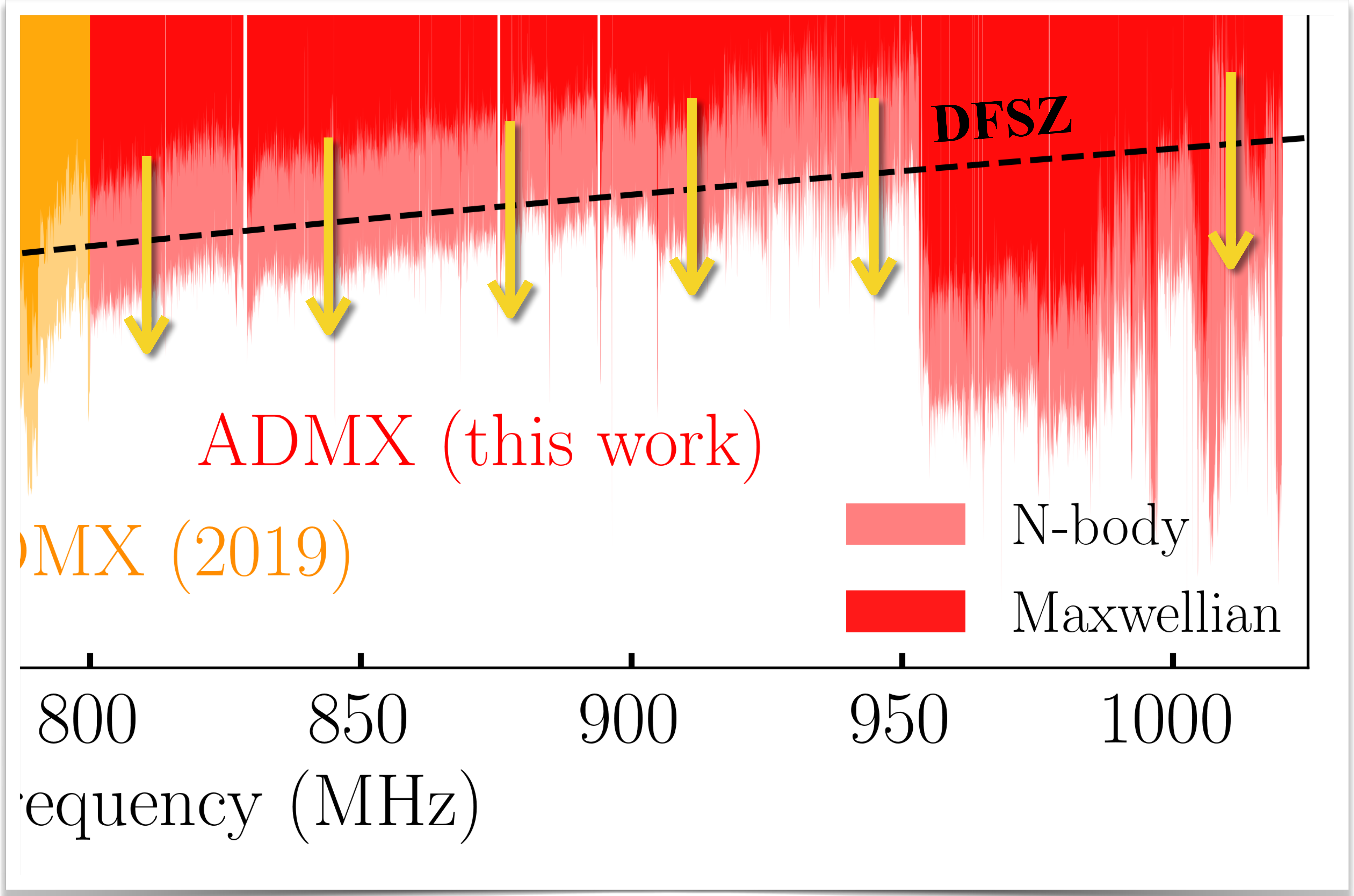
~ 970 MHz



N-body: 0.6 GeV/cc

Maxwellian: 0.45 GeV/cc

What's next?



Plan to search DFSZ axions for the whole range

Need lower T_{sys} from 600 to 200-300 mK

→ Extract detectors and upgrade detectors

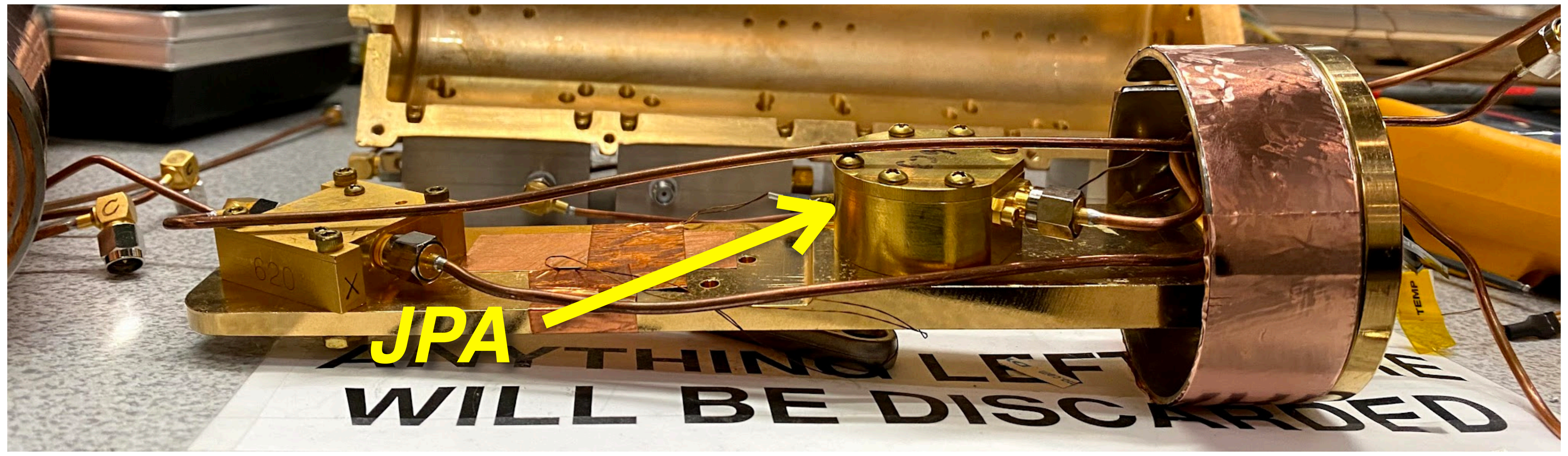
Upgrades

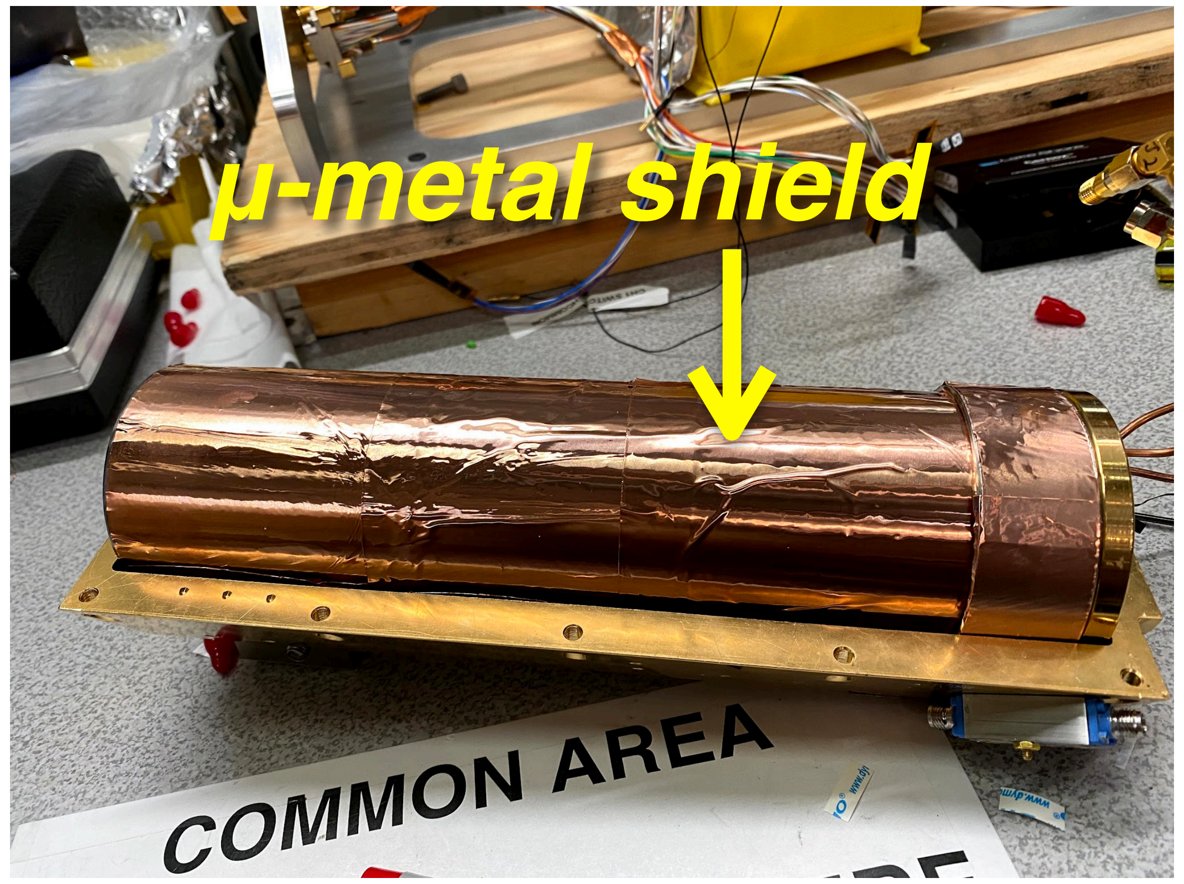
Cooler Cavity

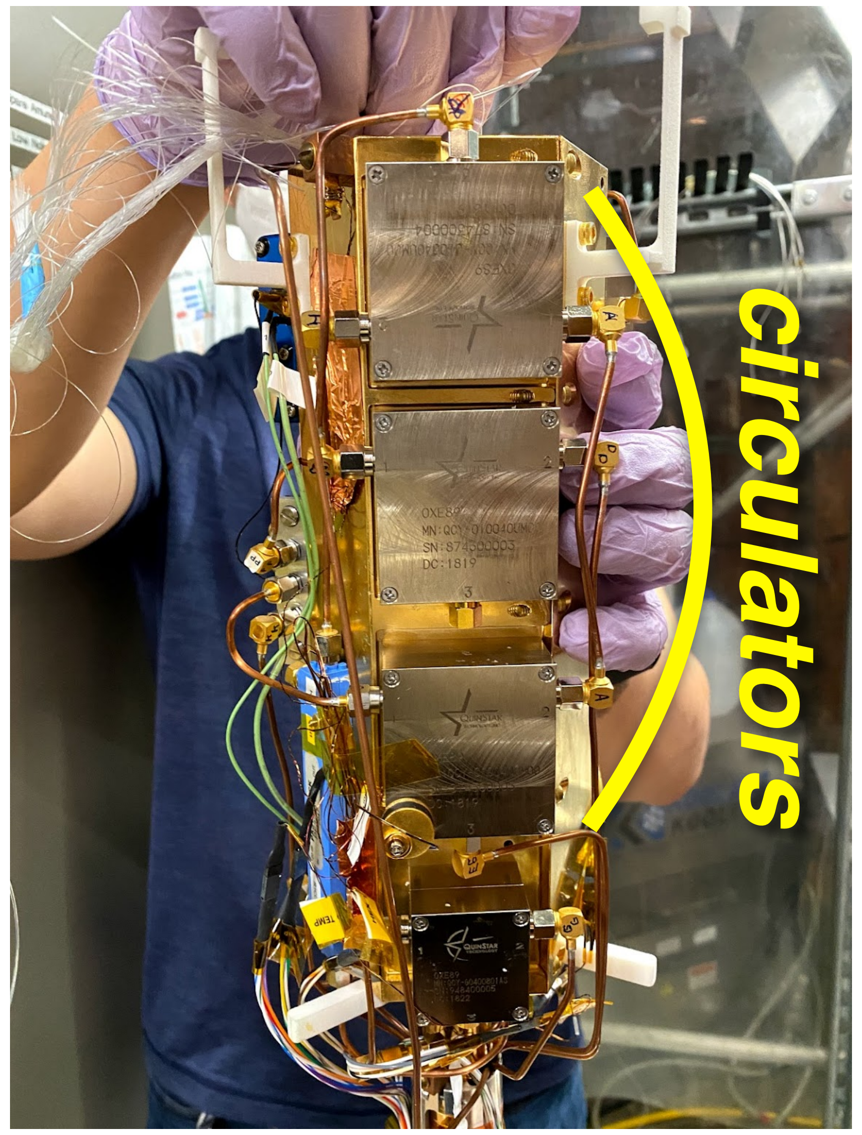
Heat flow: 70 ->12μW

Temp: 150 -> 100 mK (exp.)

Ensure Quantum Device Performance

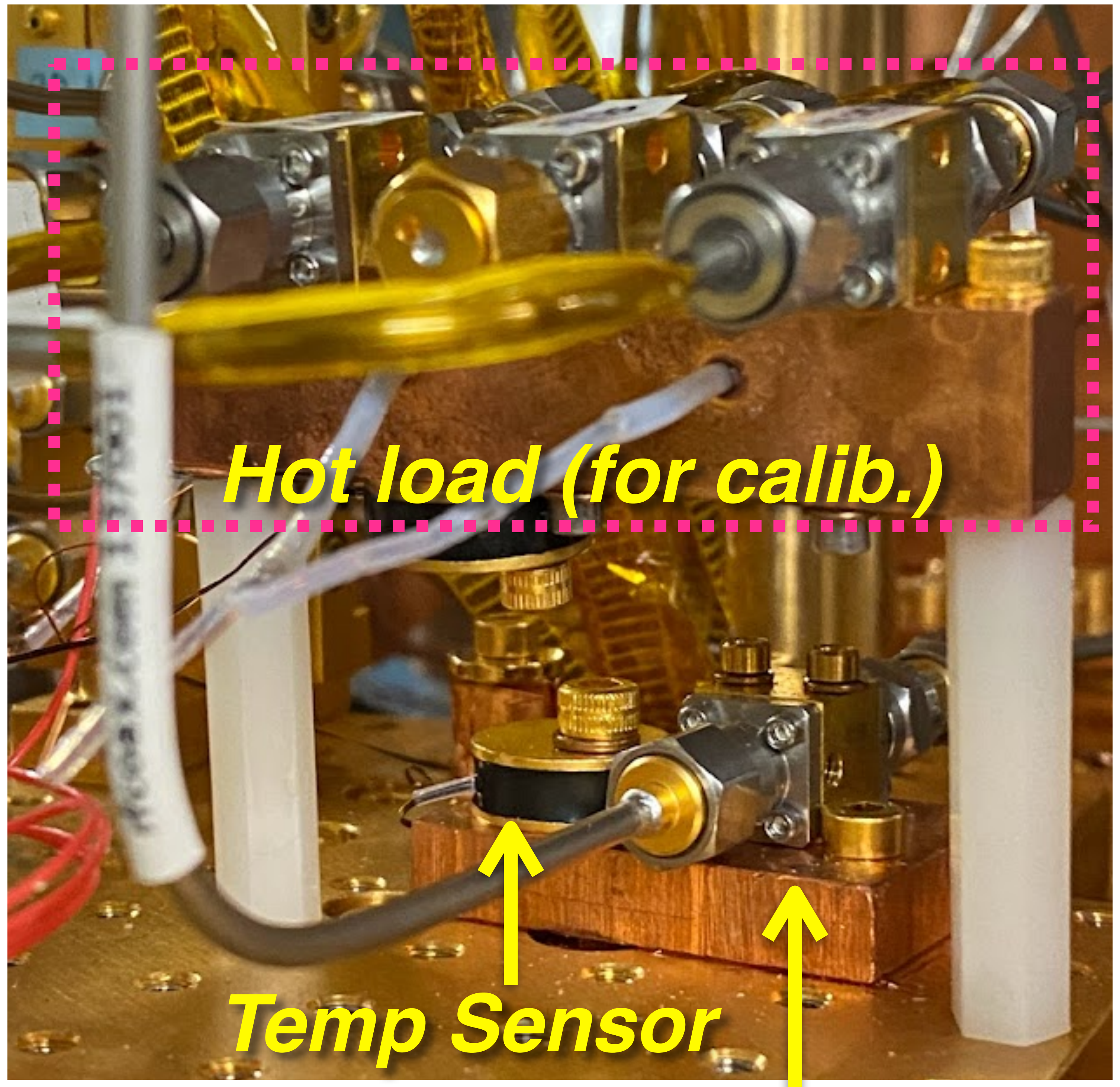






- Aluminium $H_c \sim 0.01$ T
- squid possibly traps flux quantum

Improved Calibration System

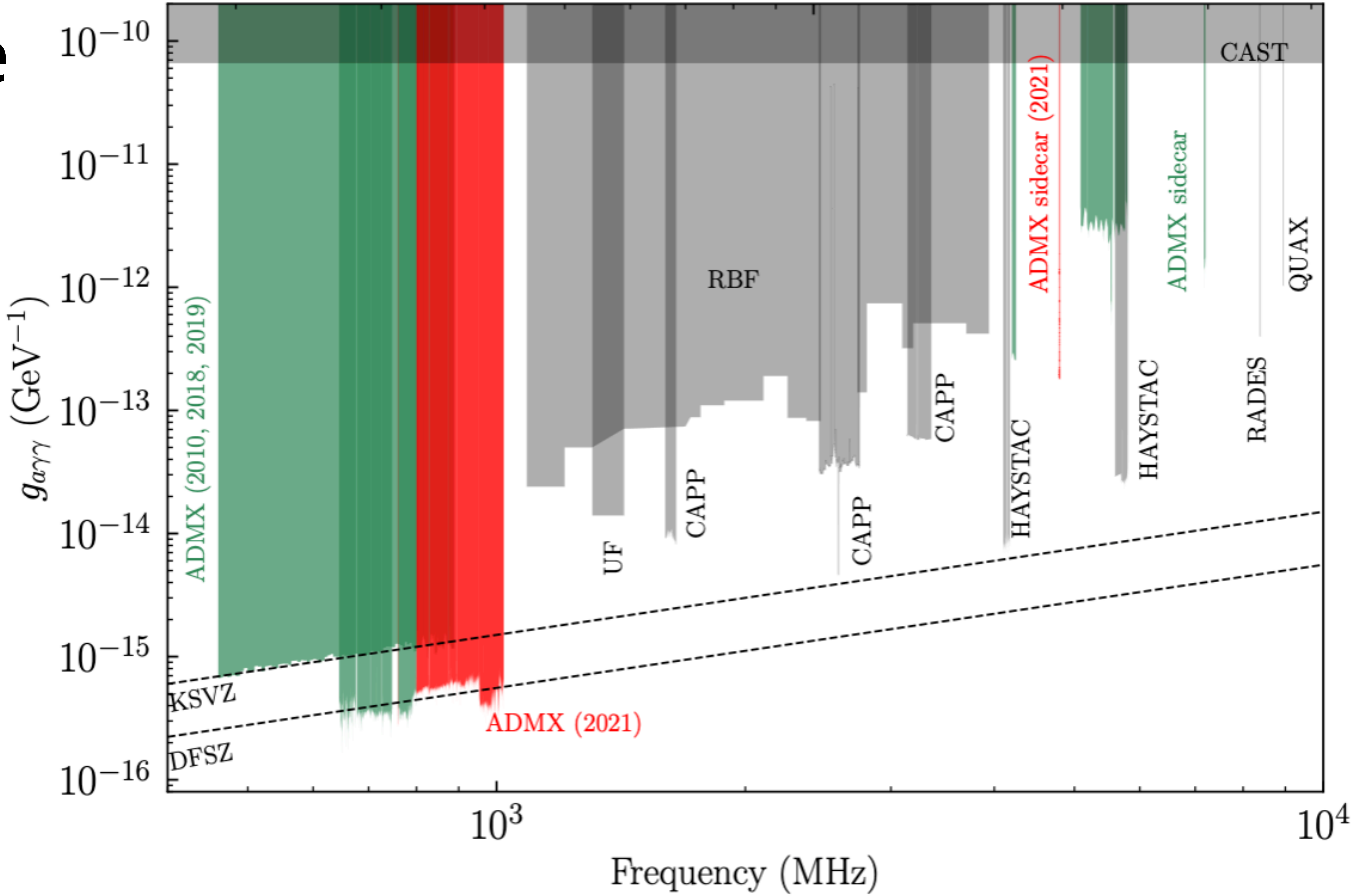


Attenuator (dictate JPA noise)

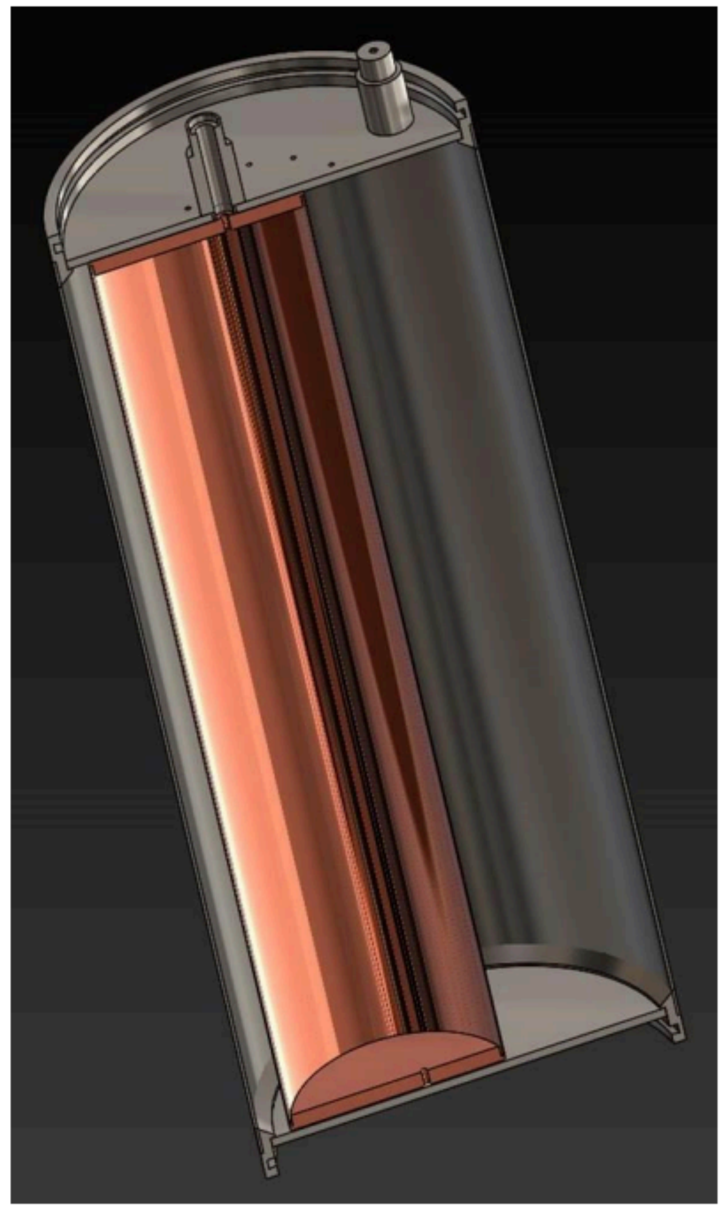
$T_{\text{hotload}} > 500 \to 100$ mK

Add temperature sensor

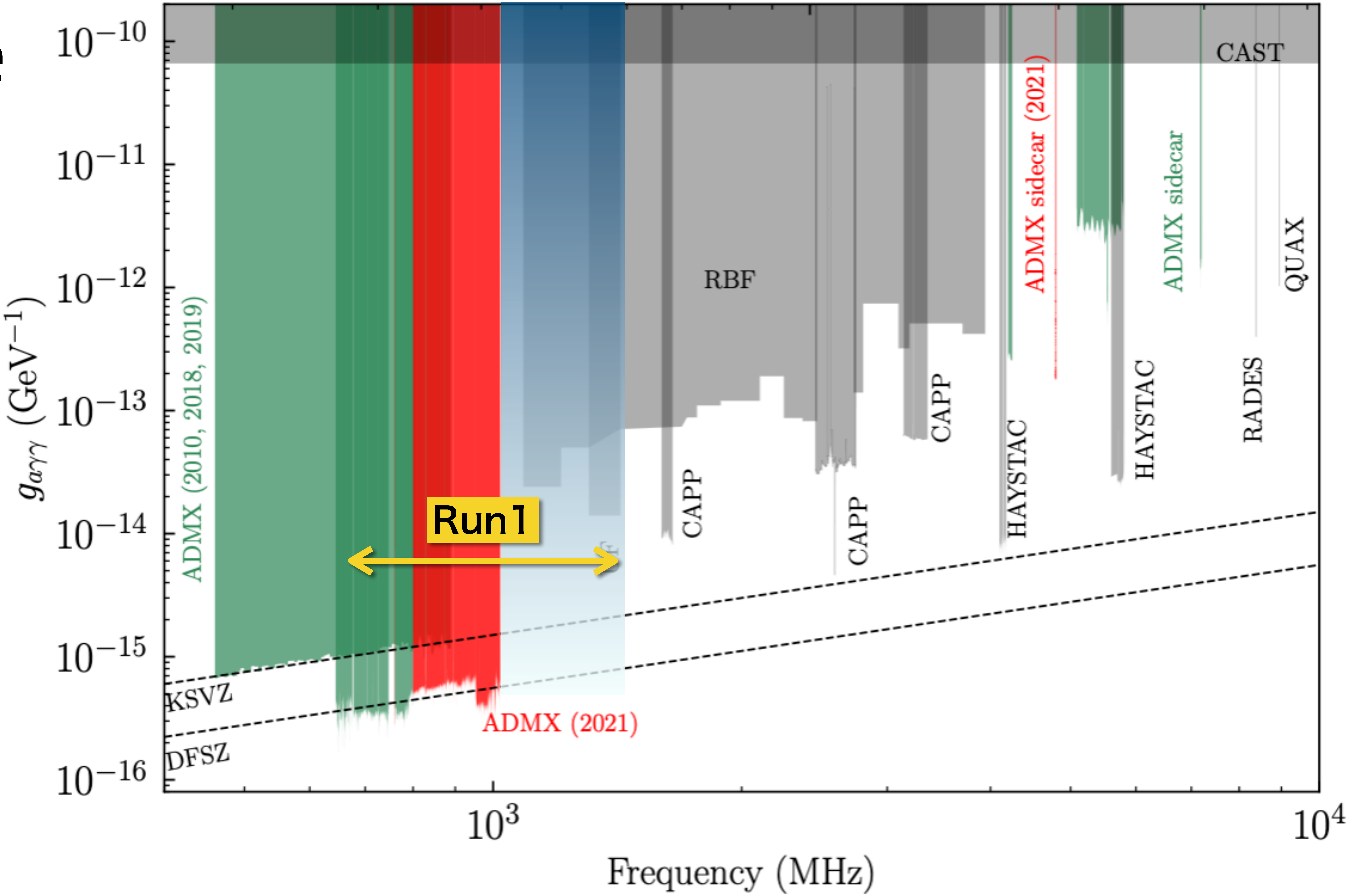
Future Plans



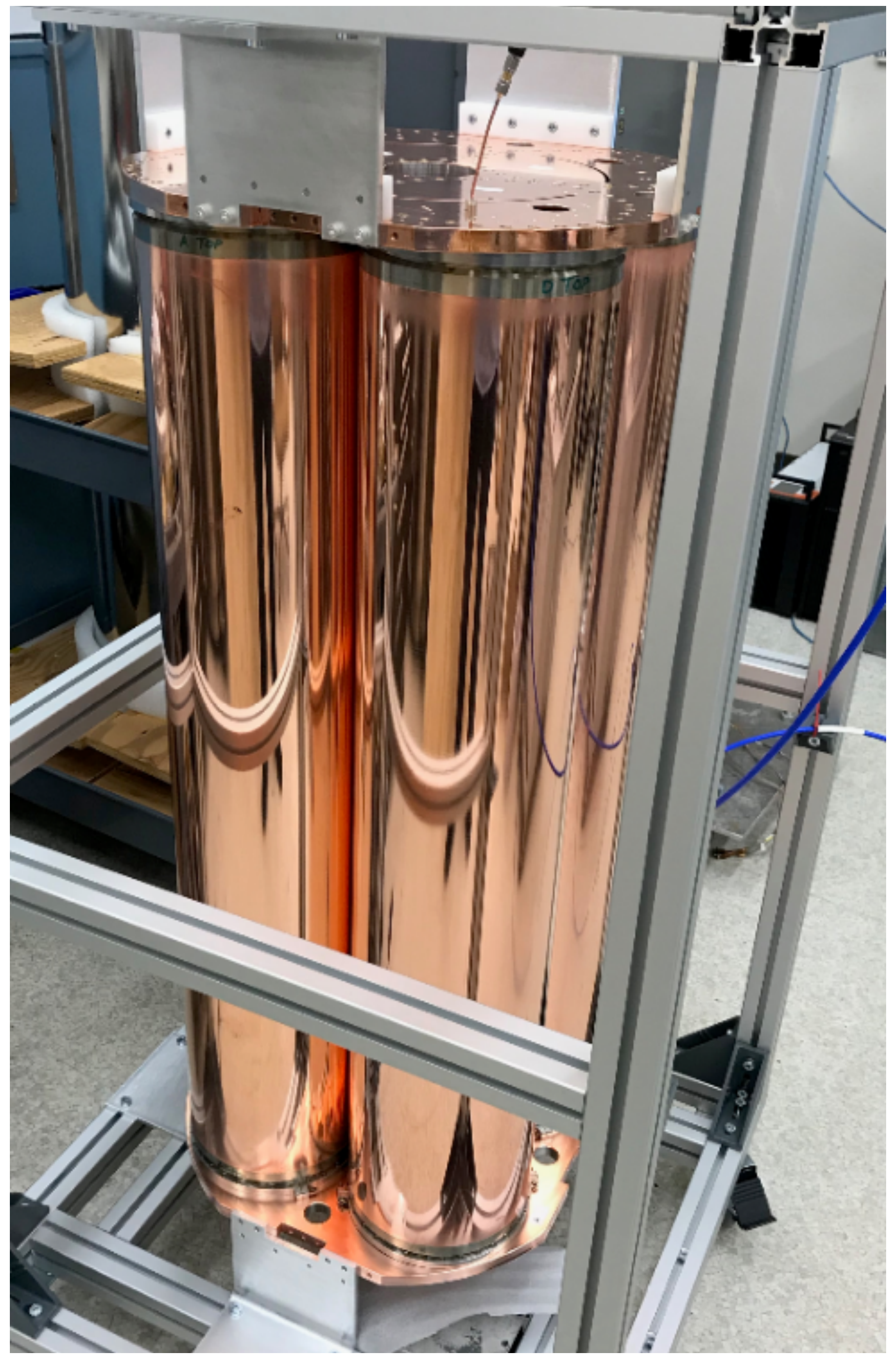
Future Plans



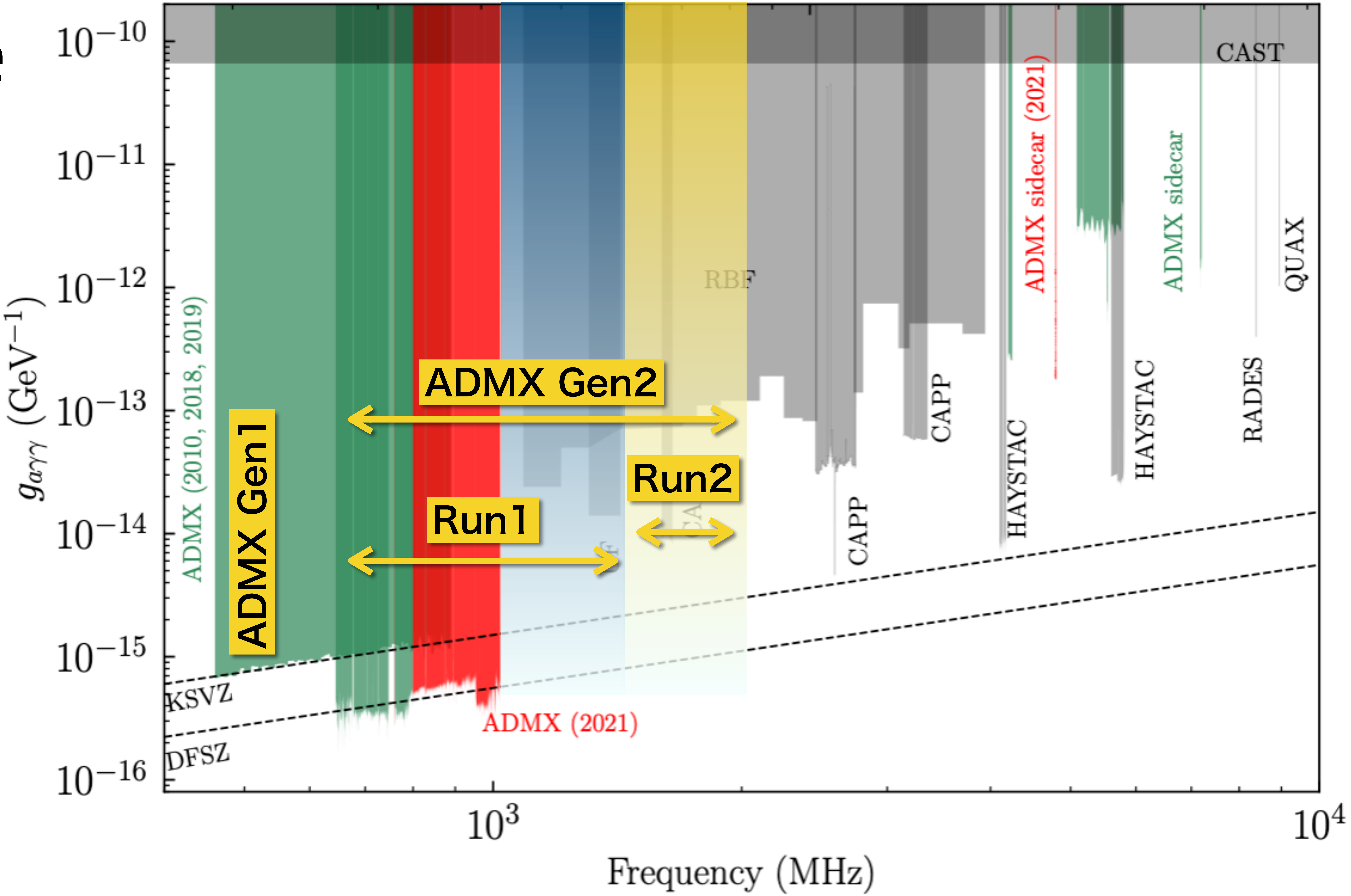
Bigger tuning rod



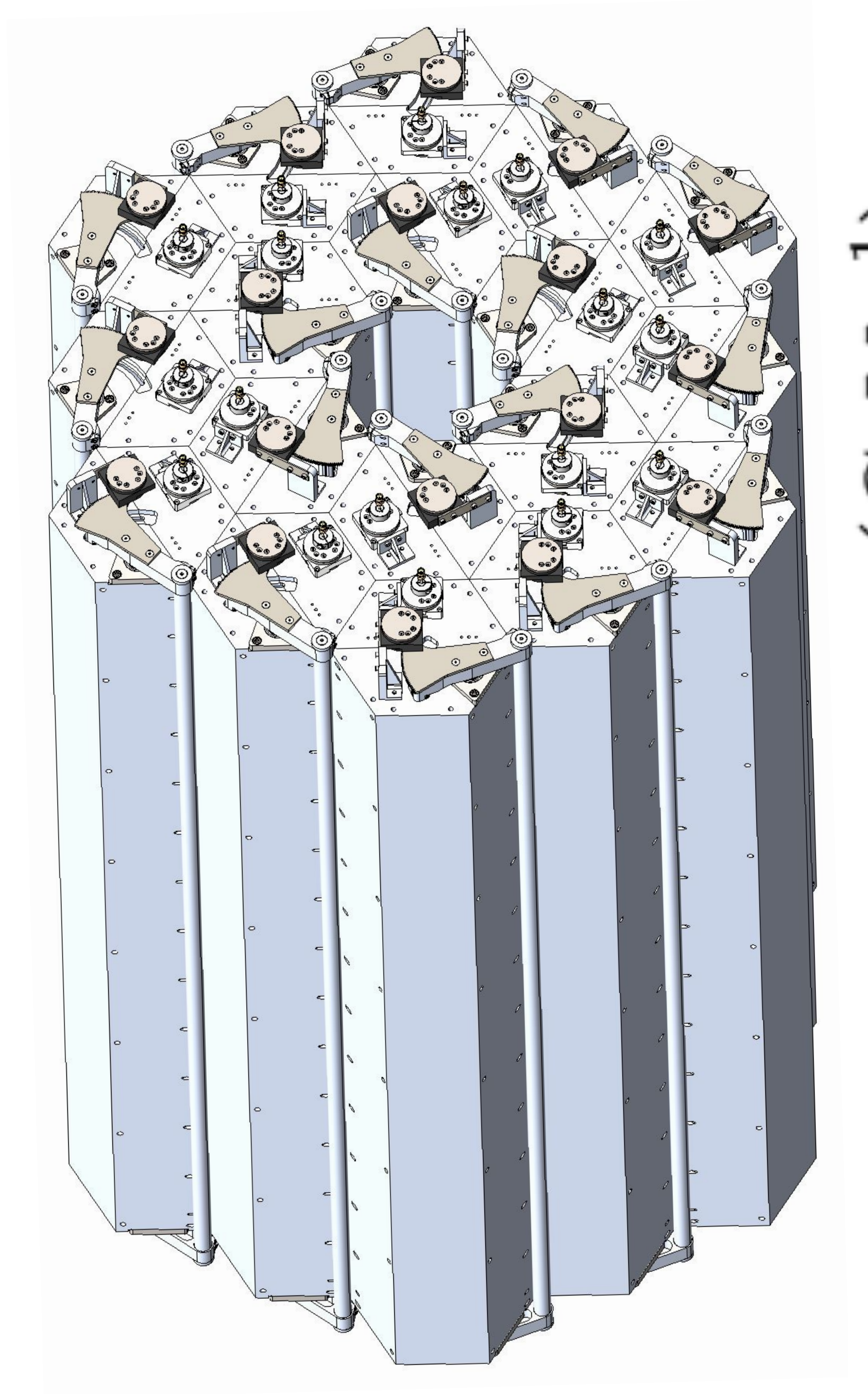
Future Plans



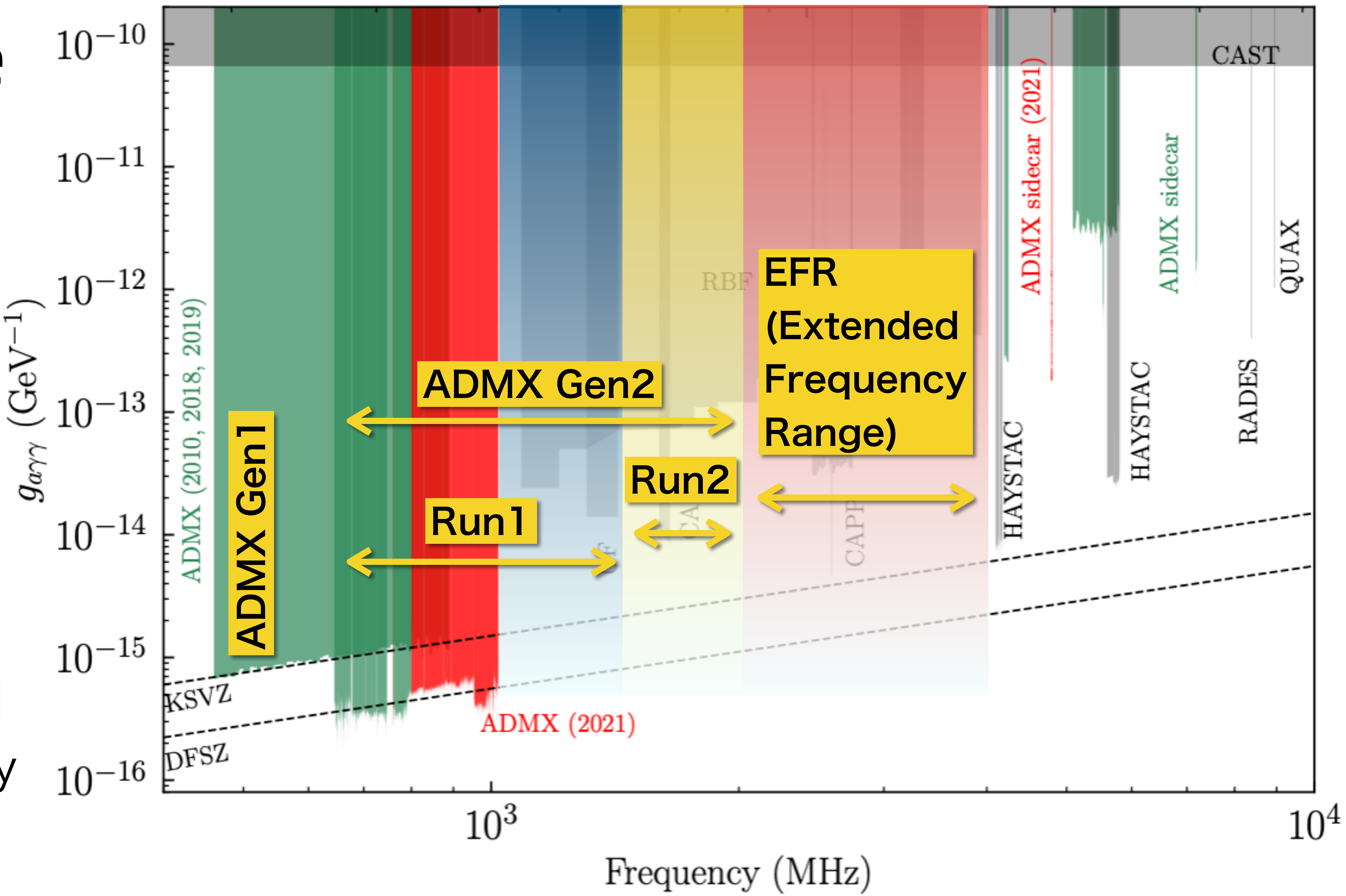
4-cavity array



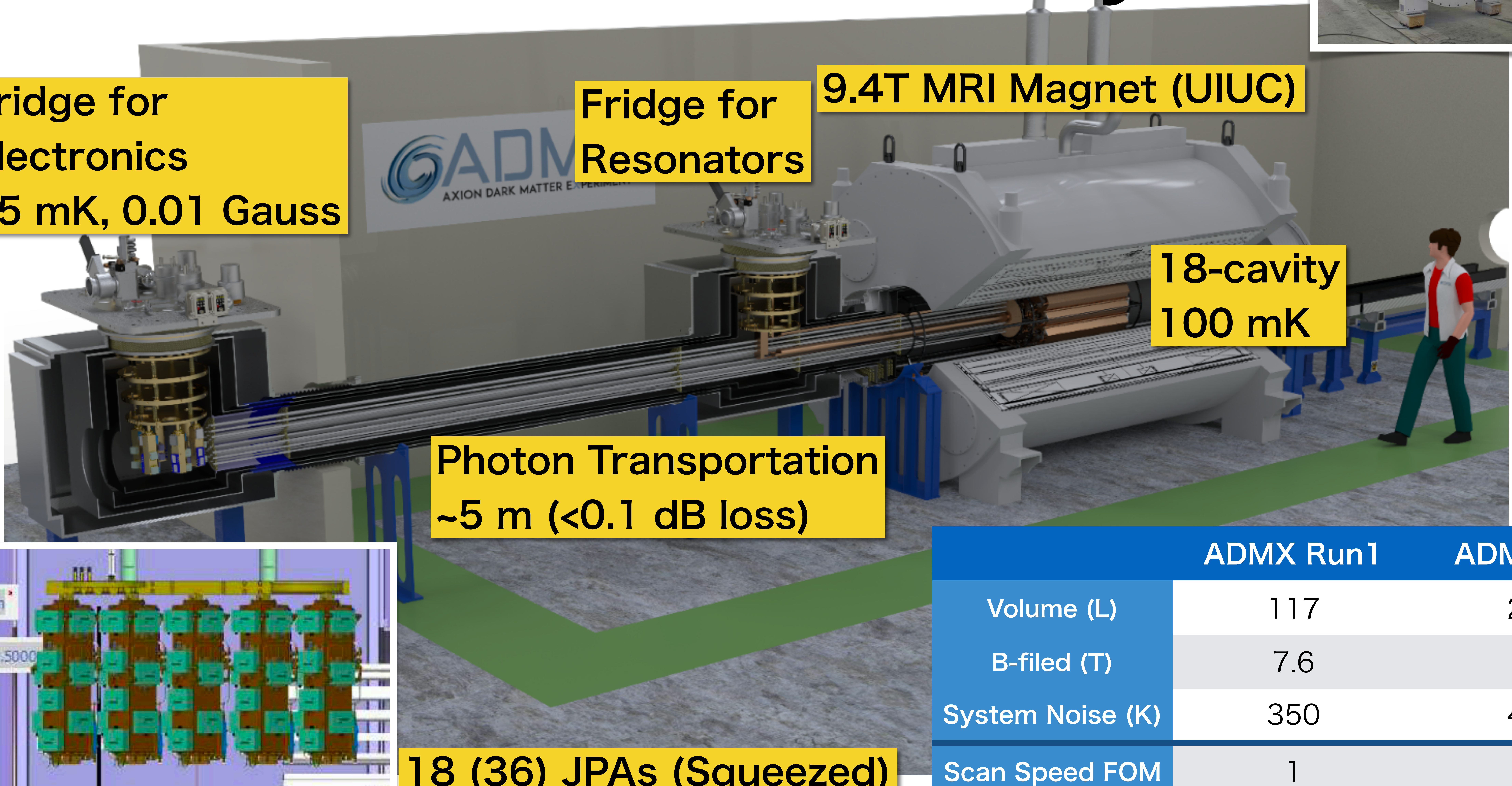
Future Plans



18-cavity array



ADMX EFR (18-Cavity)



	ADMX Run1	ADMX EFR
Volume (L)	117	258
B-filed (T)	7.6	9.4
System Noise (K)	350	425
Scan Speed FOM	1	4.8

Summary

Ruled out one of the “invisible” axion model in $m_a = 3.3 - 4.2\ \mu\text{eV}$

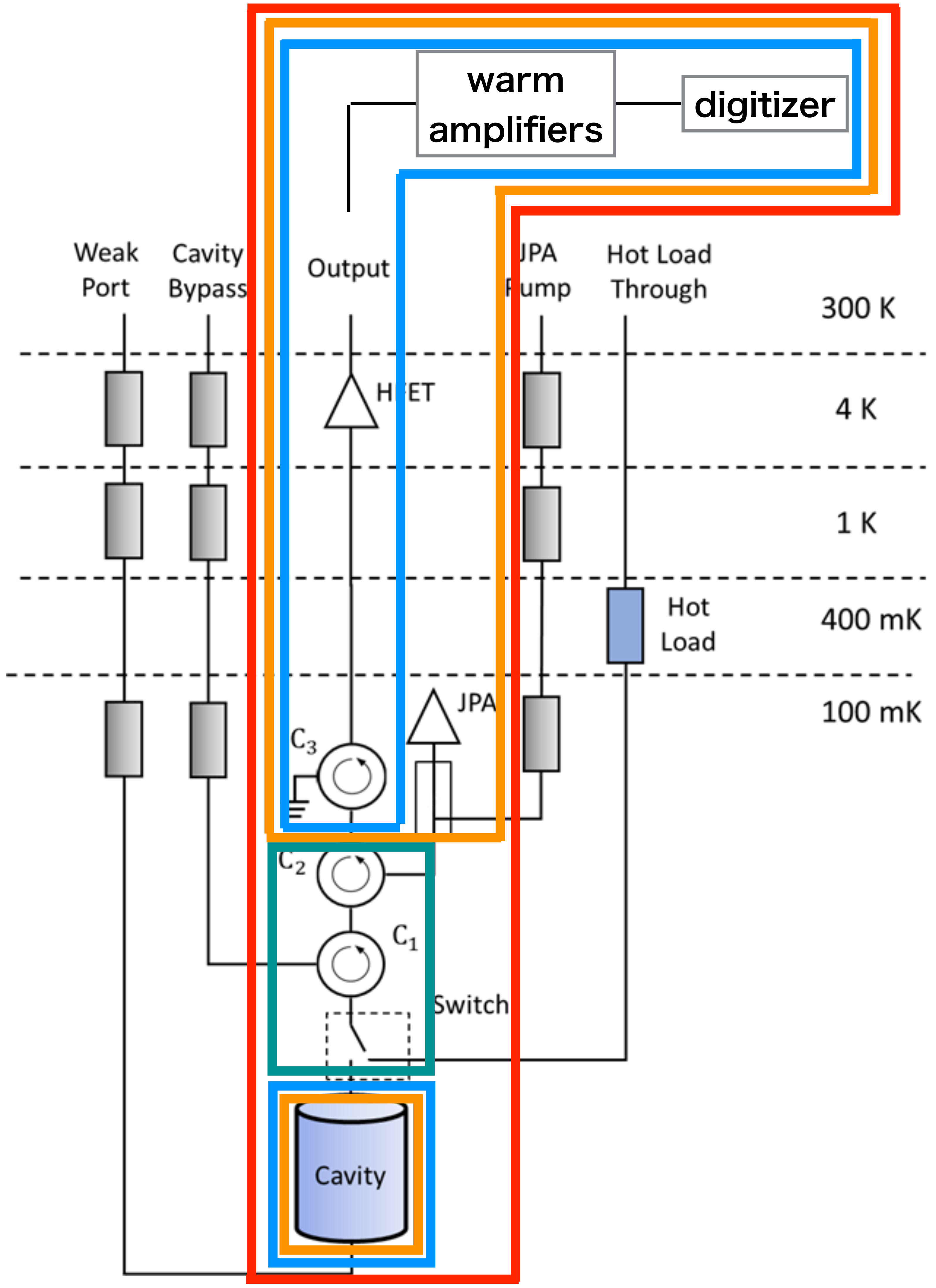
Several improvements were implemented

We plan to search DFSZ axions for whole the $m_a = 3.3 - 4.2\ \mu\text{eV}$ range

This work was supported by the U.S. Department of Energy through Grants No. DE-SC0009800, No. DESC0009723, No. DE-SC0010296, No. DE-SC0010280, No. DE-SC0011665, No. DEFG02-97ER41029, No. DEFG02-96ER40956, No. DEAC52-07NA27344, No. DEC03-76SF00098, and No. DE-SC0017987. Fermilab is a U.S. Department of Energy, Office of Science, HEP User Facility. Fermilab is managed by Fermi Research Alliance, LLC (FRA), acting under Contract No. DE- AC02-07CH11359. Additional support was provided by the Heising-Simons Foundation and by the Lawrence Livermore National Laboratory and Pacific Northwest National Laboratory LDRD offices. UWA participation is funded by the ARC Centre of Excellence for Engineered Quantum Systems, CE170100009, Dark Matter Particle Physics, CE200100008, and Forrest Research Foundation. Speaker of this talk is supported by JSPS Overseas Research Fellowships No. 202060305. LLNL Release No. LLNL-JRNL-826807.

Backup

System noise measurement



$$\mathrm{SNR} = \frac{P_{\mathrm{sig}}}{k_b T_{\mathrm{sys}}}\sqrt{\frac{t}{b}}$$

$$T_{\mathrm{sys}}^{\mathrm{JPAon}} = T_{\mathrm{phys.}} + T_{\mathrm{JPA}} + T_{\mathrm{hfet}}/G_{\mathrm{JPA}} + \ldots$$

$$T_{\mathrm{sys}}^{\mathrm{JPAoff}} = T_{\mathrm{phys.}} + T_{\mathrm{hfet}} + \ldots$$

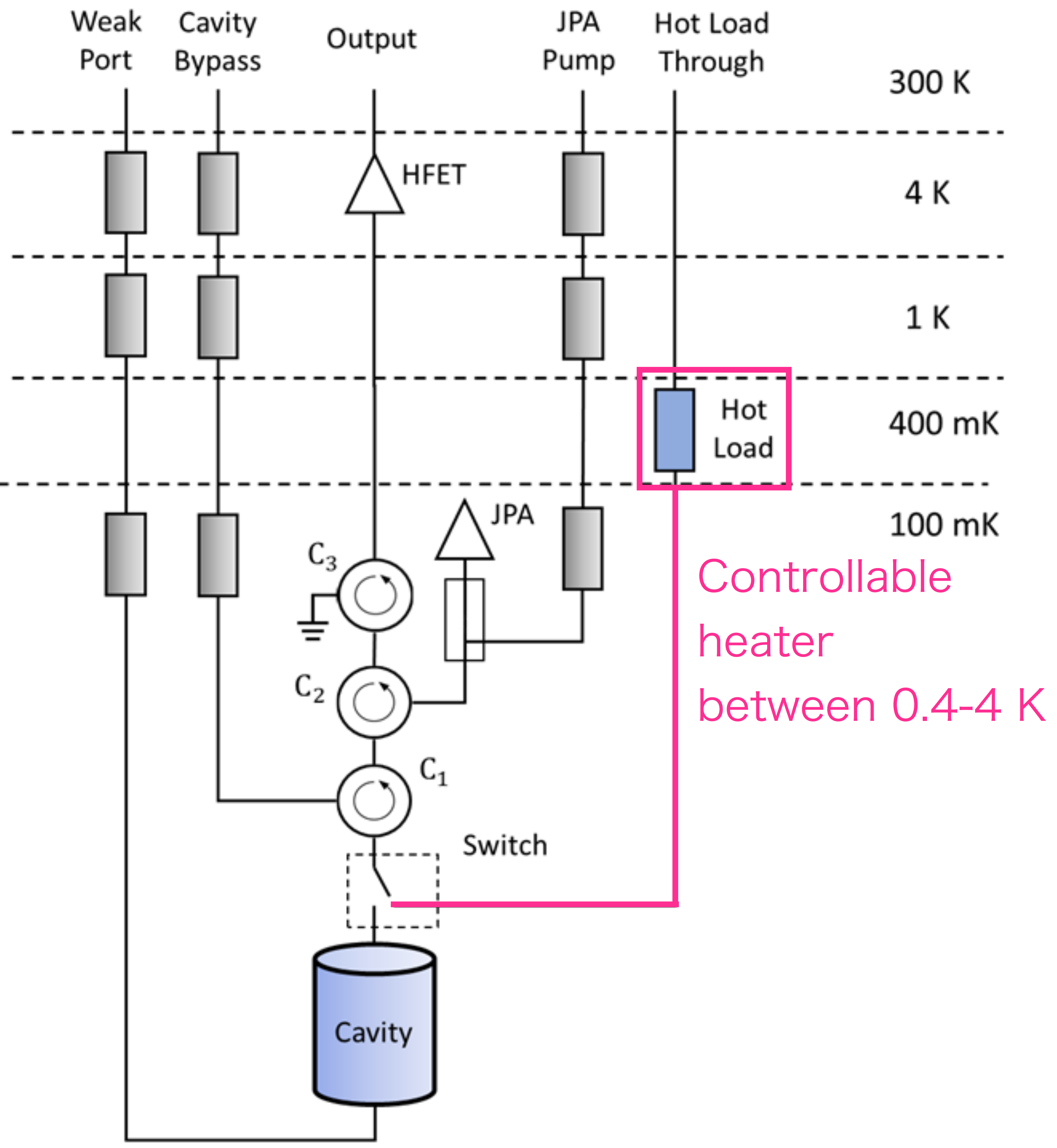
ϵ: loss between cavity and JPA

$$\mathrm{SNRI} = \frac{T_{\mathrm{sys}}^{\mathrm{JPAoff}}}{T_{\mathrm{sys}}^{\mathrm{JPAon}}} \qquad T_{\mathrm{sys}} = T_{\mathrm{sys}}^{\mathrm{JPAoff}} \;/\; \mathrm{SNRI}\ \epsilon$$

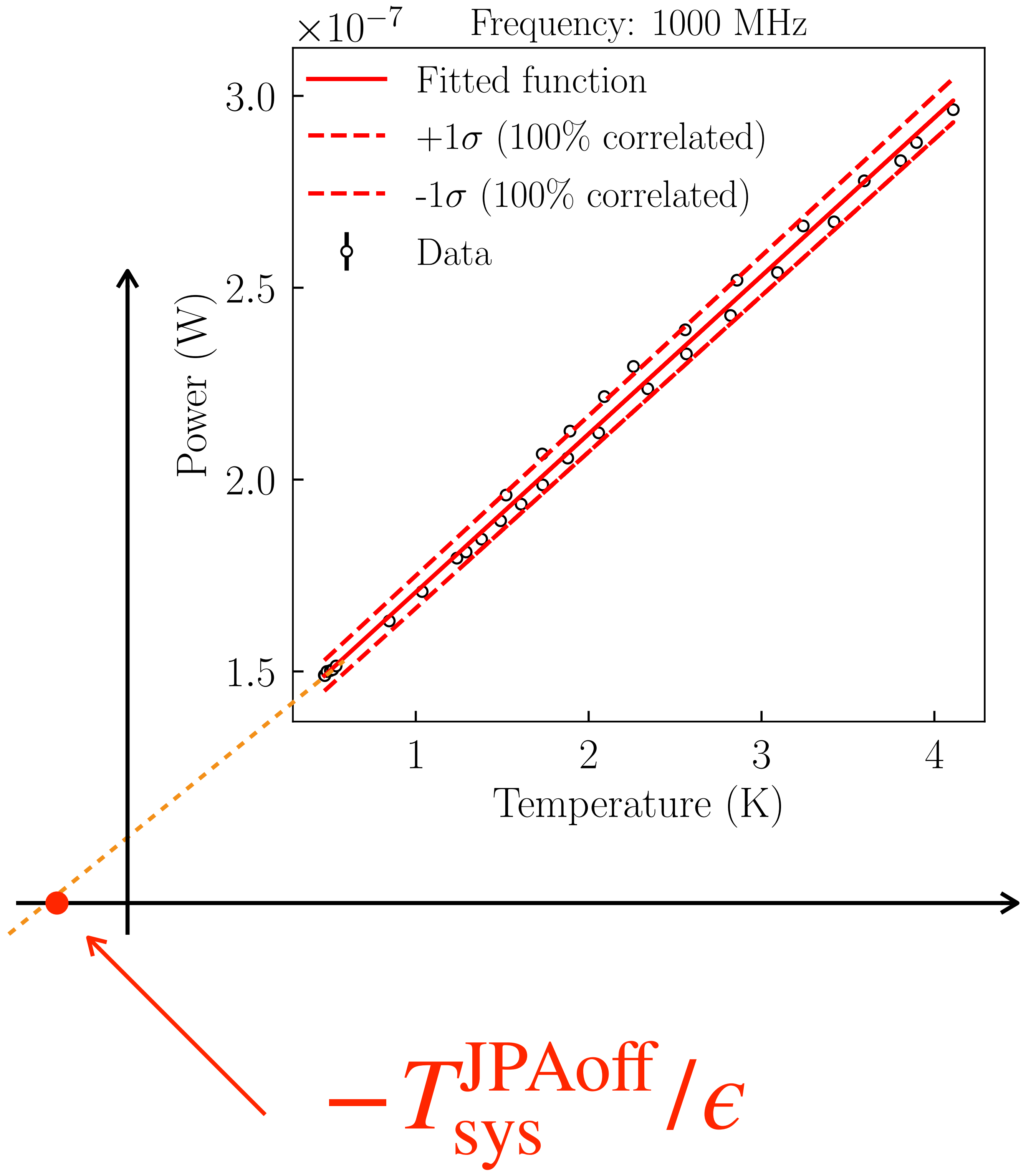
$T_{\mathrm{sys}}^{\mathrm{JPAoff}}/\epsilon$: measured with hot-cold load method

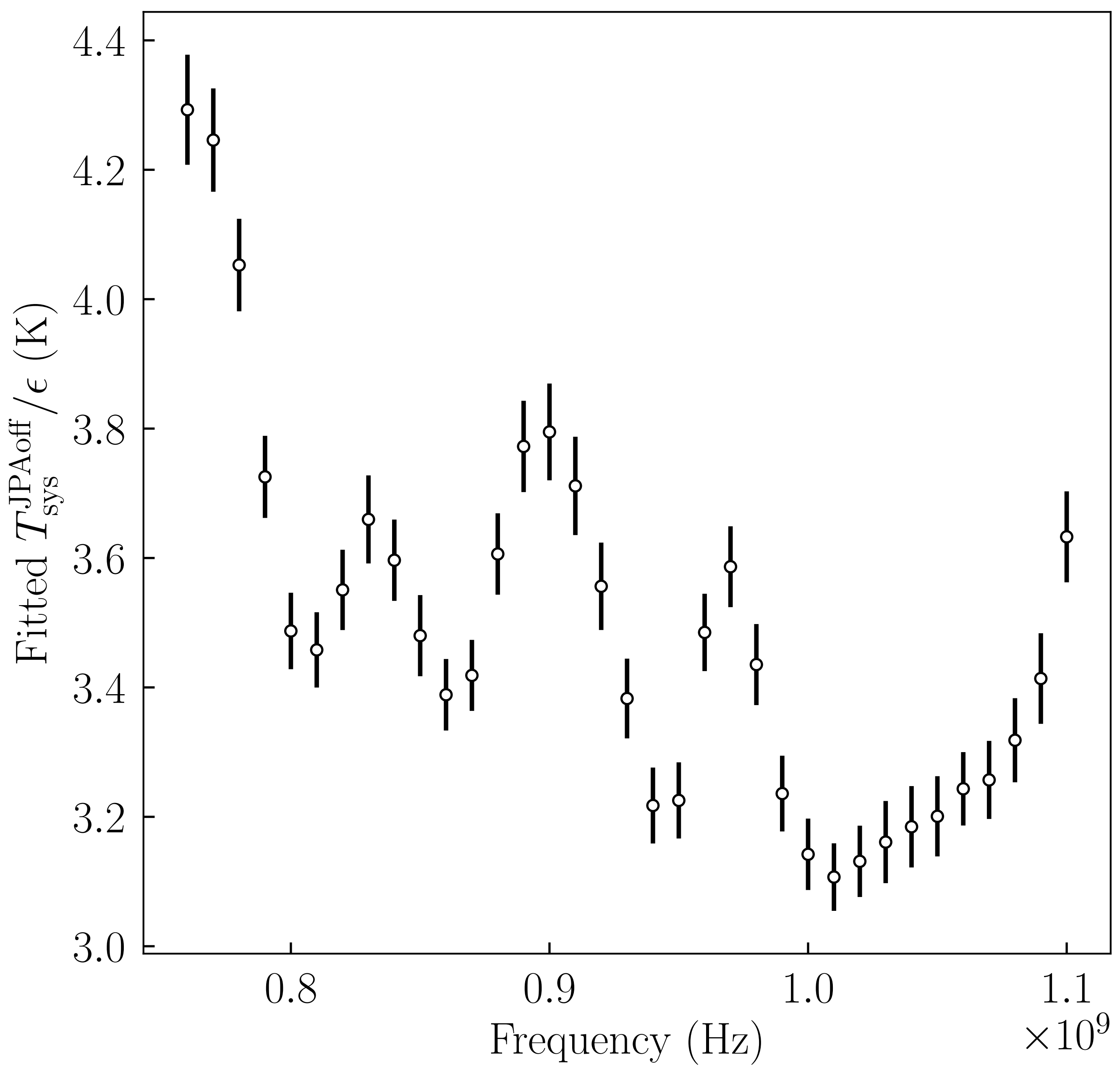
SNRI: SNRI measurement method

Hot Load Measurement



$$P = G^{\mathrm{off}}(T_{\mathrm{hot}}\epsilon + T_{\mathrm{sys}}^{\mathrm{JPAoff}})k_b b$$

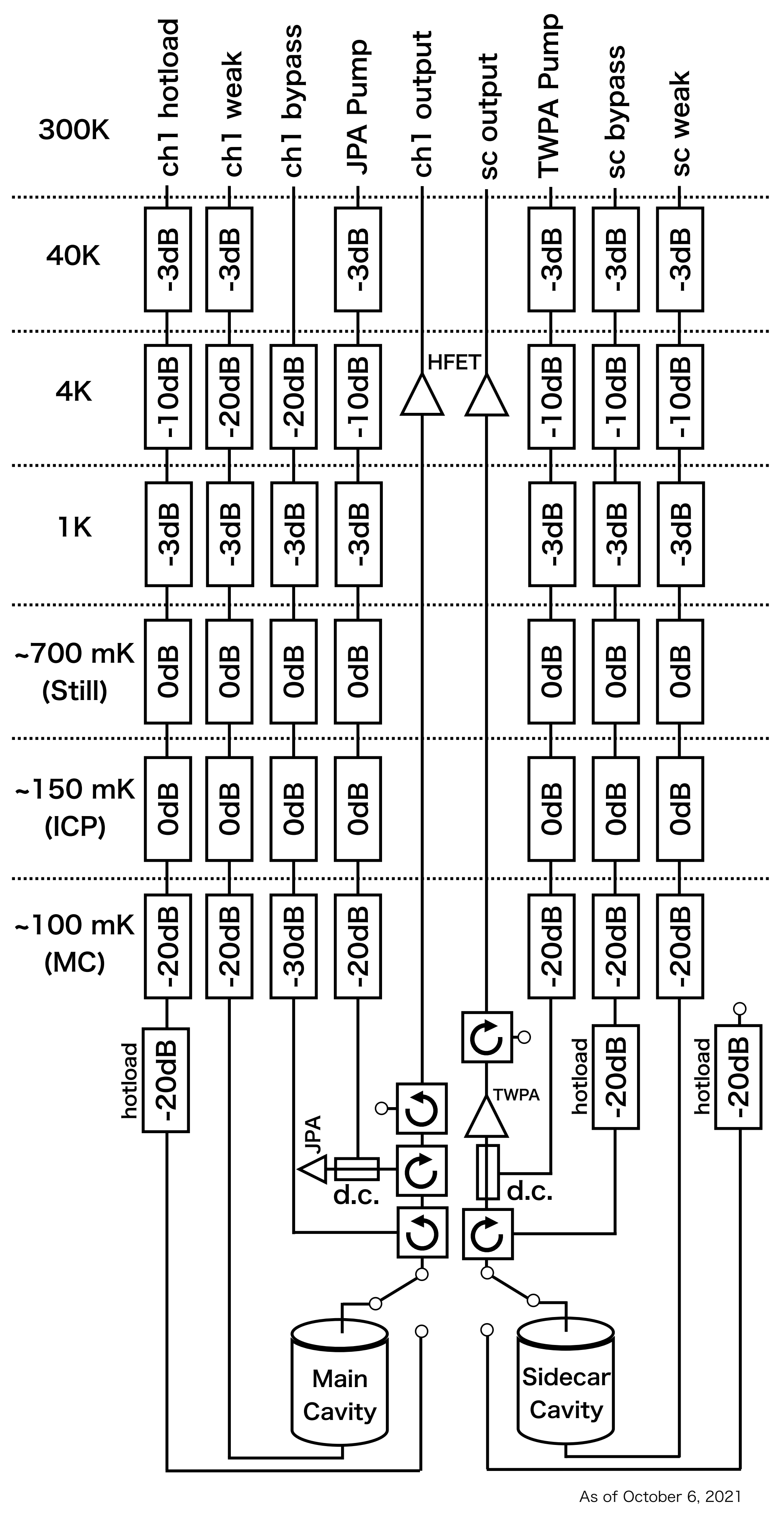




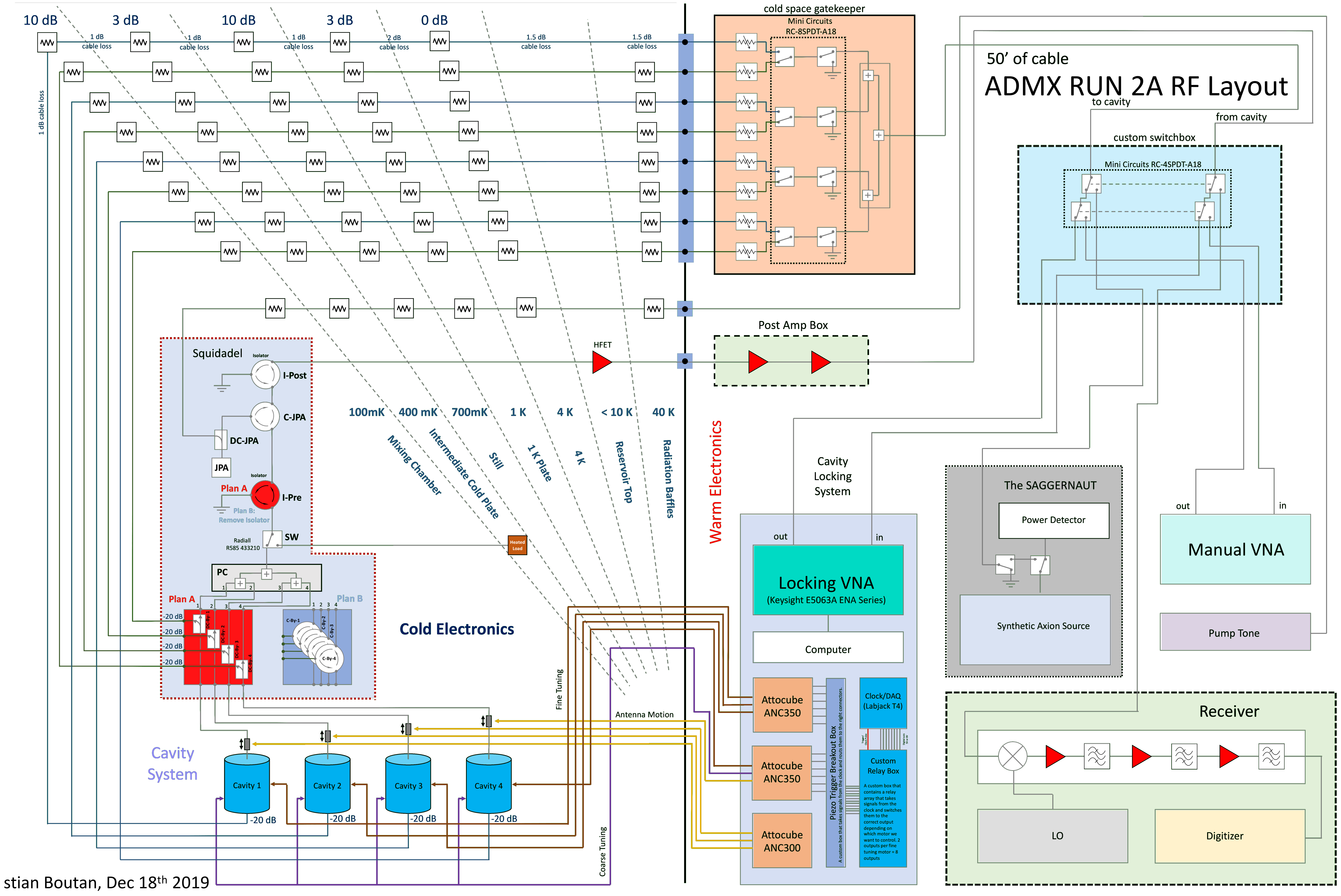
$$T_{\mathrm{sys}}^{\mathrm{JPAoff}}/\epsilon \sim 3.5\ \mathrm{K}$$

4-Cavity System

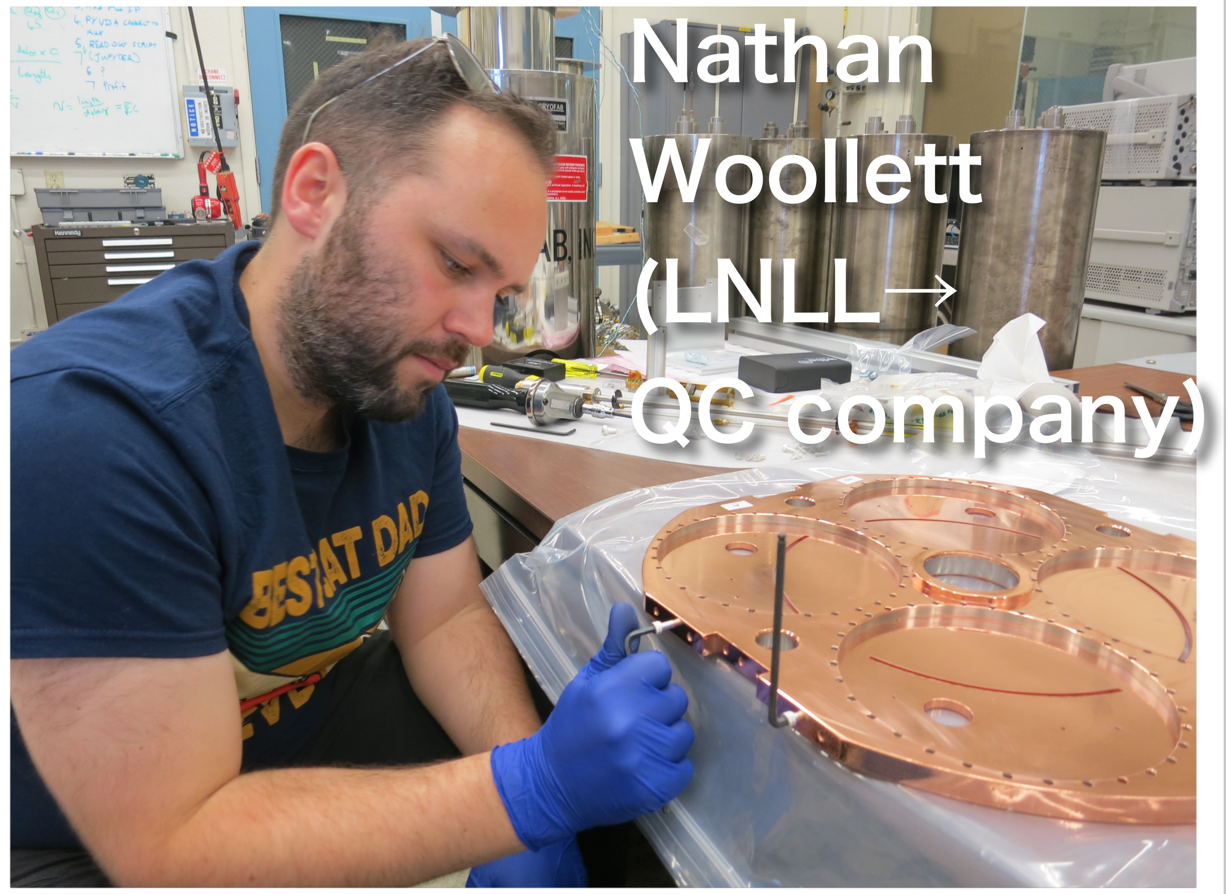
Current ADMX

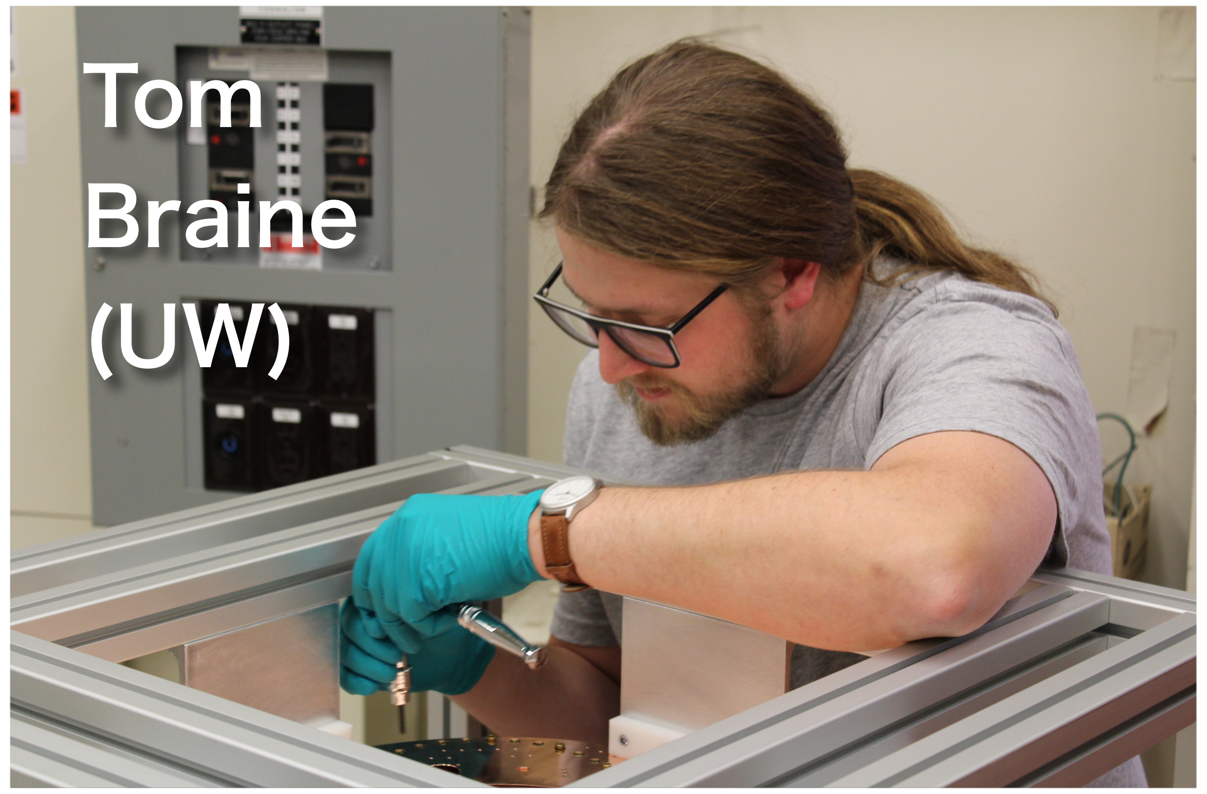


4-Cavity System

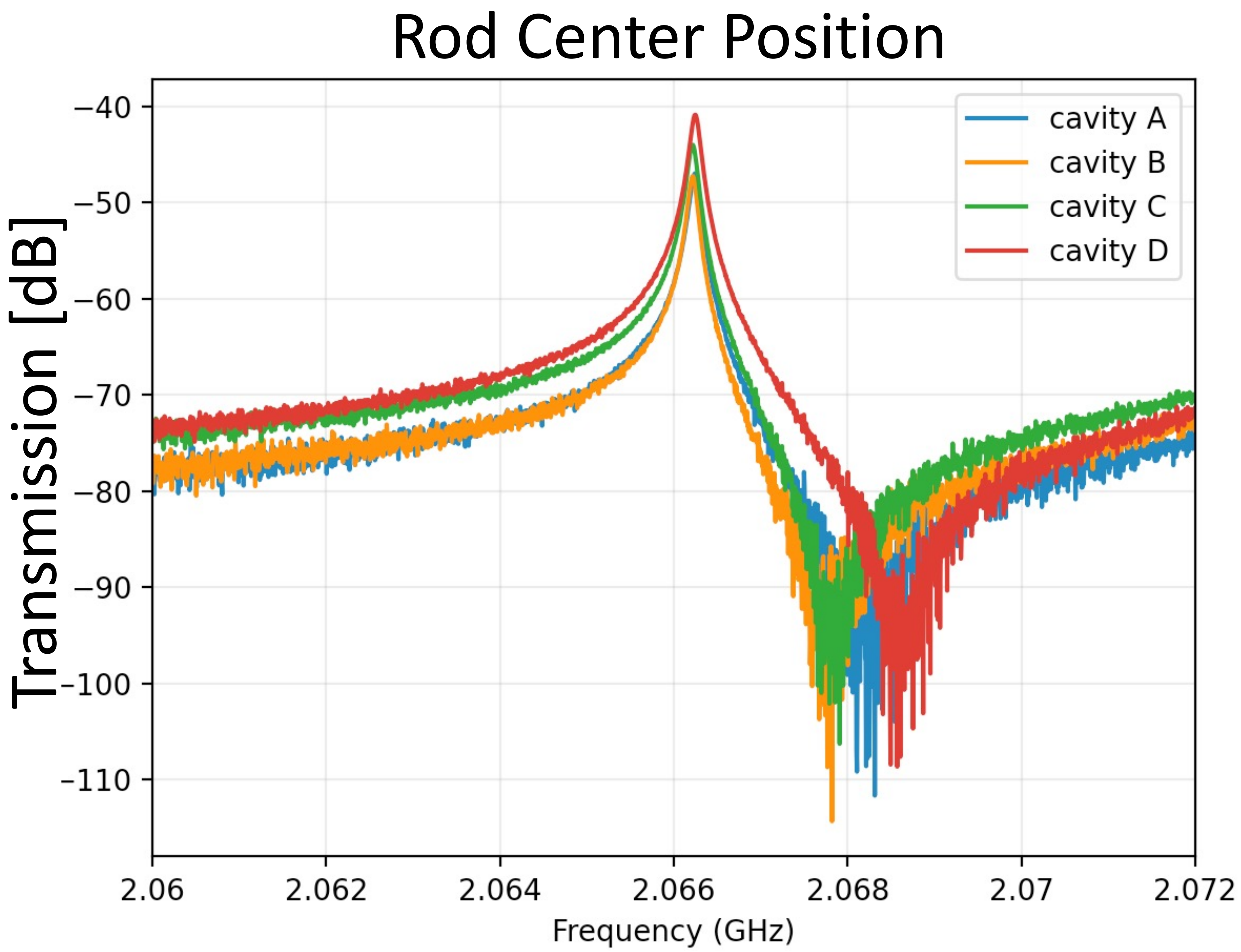


4-Cavity Array





Fabricated LLNL & Tested at FNAL now



Spread ~ 50kHz

$Q_A \sim (16.7 \pm 0.5)\mathrm{k}$

$Q_B \sim (18.7 \pm 0.5)\mathrm{k}$ @room temp

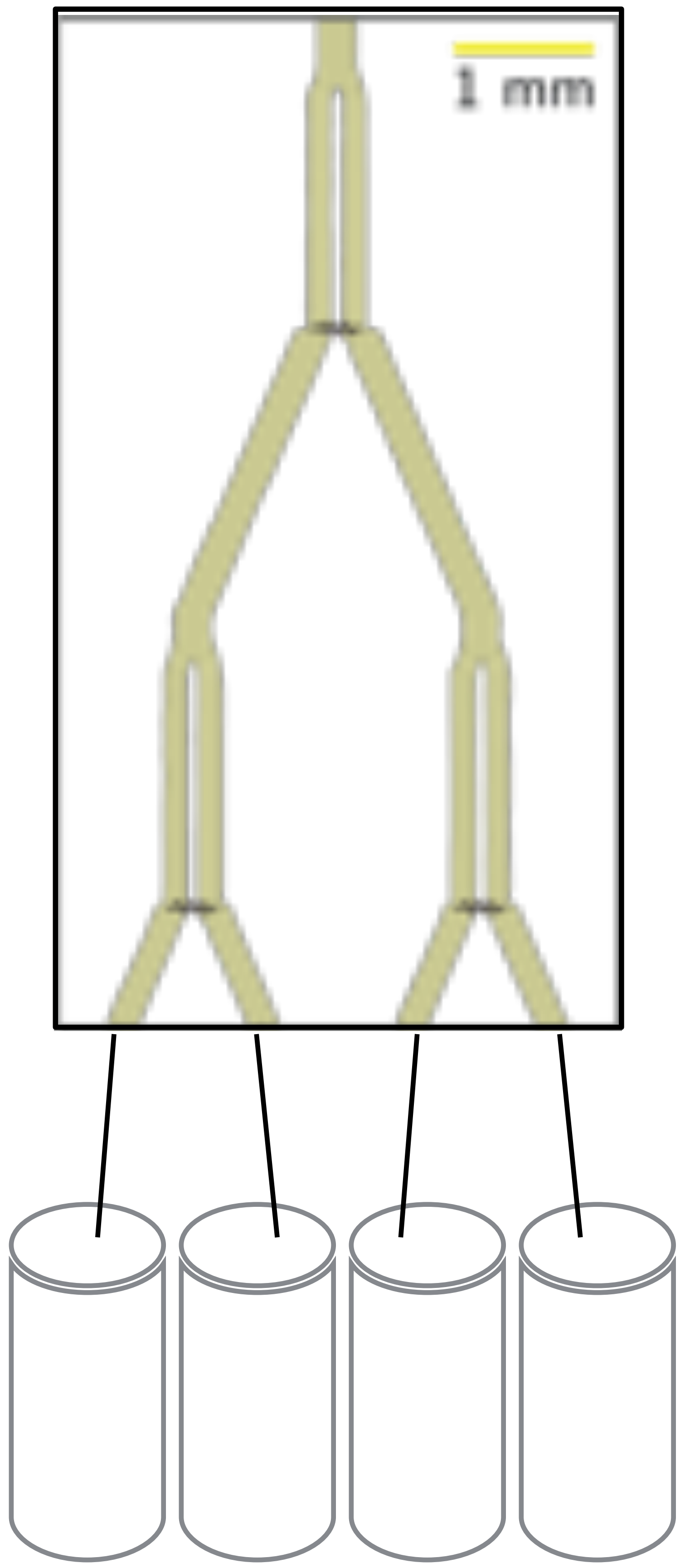
$Q_C \sim (16.8 \pm 0.5)\mathrm{k}$

$Q_D \sim (17.5 \pm 0.5)\mathrm{k}$

Promising initial results

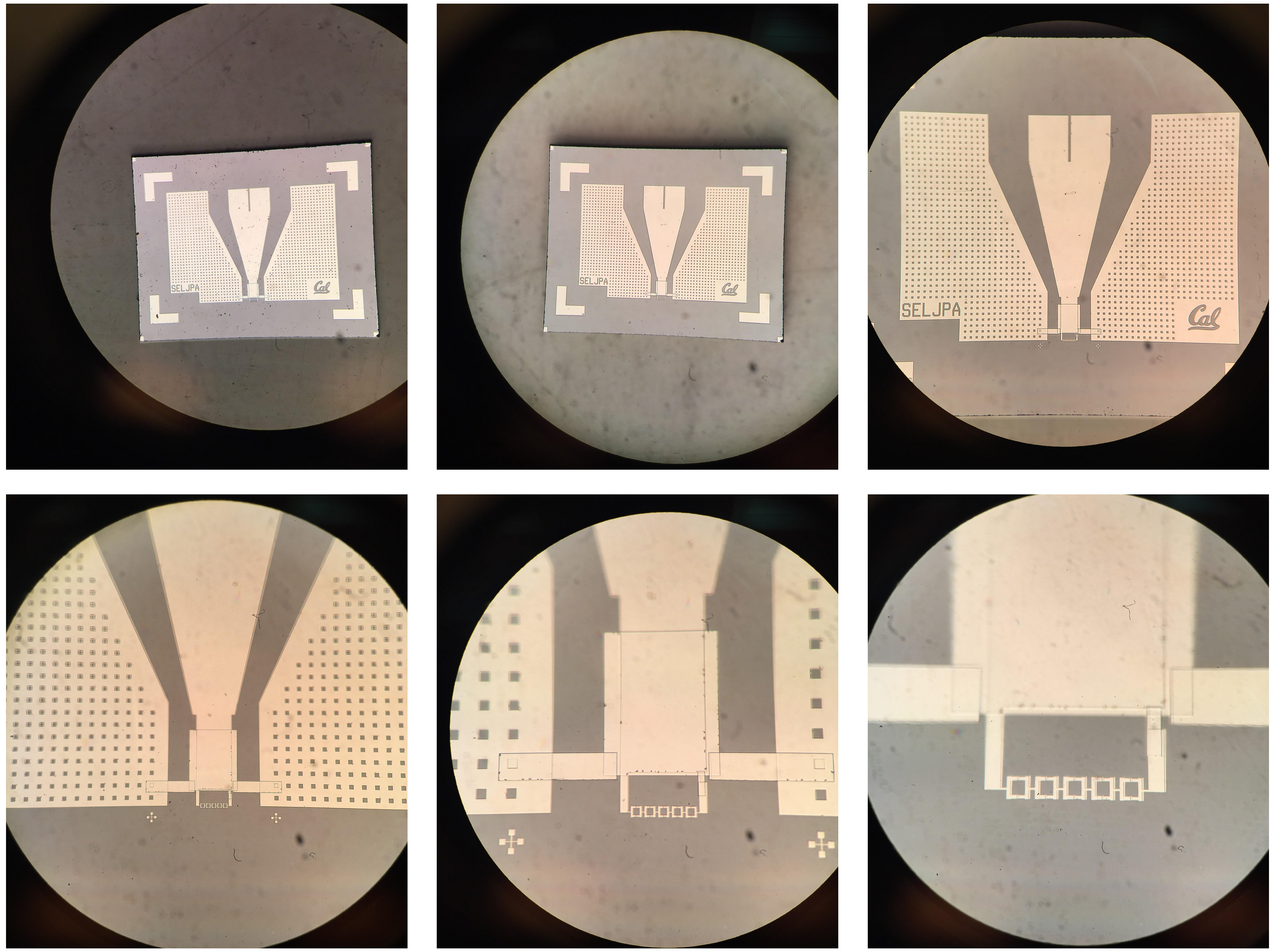
4-Cavity Electronics

Fabricated and tested at Wash U



First test indicates 0.5 dB insertion loss

Fabricated at Berkeley and tested at Wash U



Continue to use JPA

Promising performance