ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

QDm

ADMX and The ORGAN Experiment

Aaron Quiskamp

Supervisors: Michael Tobar, Ben McAllister, Maxim Goryachev

Australian Government
Australian Research Council

THE UNIVERSITY of ADELAIDE

Australian National University

THE UNIVERSITY OF MELBOURNE

SWINBURNE UNIVERSITY OF TECHNOLOGY

THE UNIVERSITY OF SYDNEY

THE UNIVERSITY OF WESTERN AUSTRALIA

Axions

Axions

- **Axions** can solve two very big problems in physics!

Axions

- **Axions** can solve two very big problems in physics!
- Strong CP problem: Why is **charge-parity (CP)** symmetry conserved in QCD?

Axions

- **Axions** can solve two very big problems in physics!
- Strong CP problem: Why is **charge-parity (CP)** symmetry conserved in QCD?
- **Peccei-Quinn (PQ)** symmetry (1977): A new global symmetry that when broken gives rise to a pseudoscalar field → **Axion**

Axions

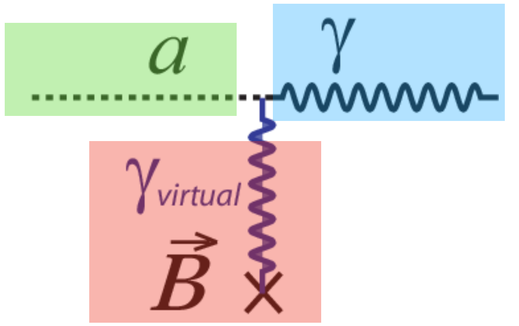
- **Axions** can solve two very big problems in physics!
- Strong CP problem: Why is **charge-parity (CP)** symmetry conserved in QCD?
- **Peccei-Quinn (PQ)** symmetry (1977): A new global symmetry that when broken gives rise to a pseudoscalar field → **Axion**
- The QCD Axion solves the strong **CP problem**

Axions

- **Axions** can solve two very big problems in physics!
- Strong CP problem: Why is **charge-parity (CP)** symmetry conserved in QCD?
- **Peccei-Quinn (PQ)** symmetry (1977): A new global symmetry that when broken gives rise to a pseudoscalar field → **Axion**
- The QCD Axion solves the strong **CP problem**
- **AND** the properties of axions also make them a popular **dark matter** candidate

Axions

- **Axions** can solve two very big problems in physics!
- Strong CP problem: Why is **charge-parity (CP)** symmetry conserved in QCD?
- **Peccei-Quinn (PQ)** symmetry (1977): A new global symmetry that when broken gives rise to a pseudoscalar field → **Axion**
- The QCD Axion solves the strong **CP problem**
- **AND** the properties of axions also make them a popular **dark matter** candidate
- Axions may interact with a strong **B** field to produce a photon with frequency related to m_a



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

How to detect axions?

How to detect axions?

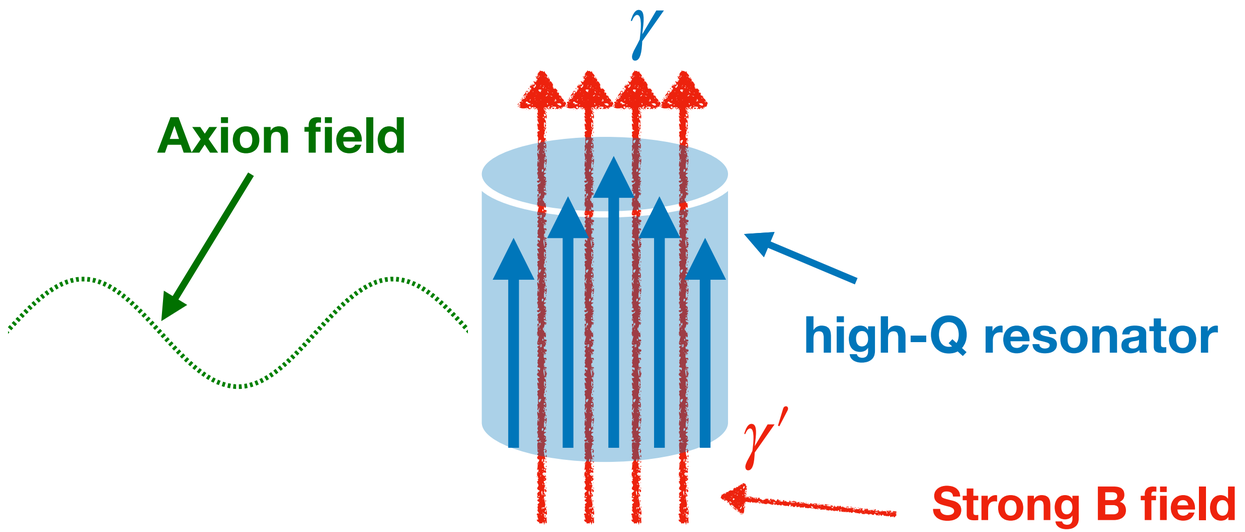
- Axion mass m_a determines the real photon frequency (f)
- $f = \frac{m_a}{h}c^2 + \frac{1}{2}\frac{m_a}{h}v^2$

How to detect axions?

- Axion mass m_a determines the real photon frequency (f)

$$P_{\text{signal}} = g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} B_0^2 V C Q_L \frac{\beta}{1+\beta}$$

- $f = \frac{m_a}{h}c^2 + \frac{1}{2}\frac{m_a}{h}v^2$

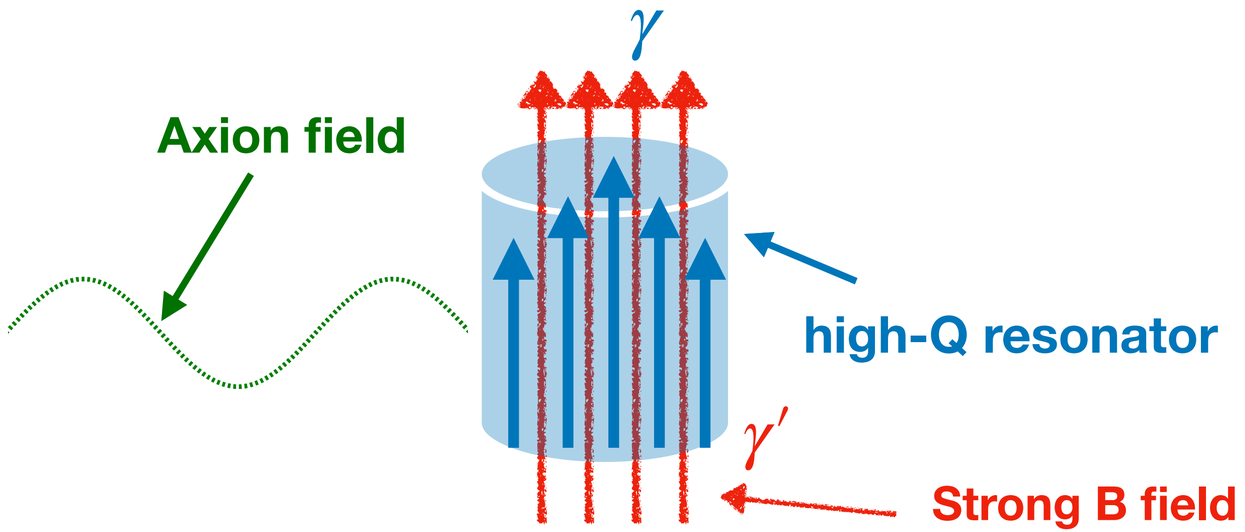


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

How to detect axions?

$$P_{\text{signal}} = g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} B_0^2 V C Q_L \frac{\beta}{1+\beta}$$

- Axion mass m_a determines the real photon frequency (f)
- $f = \frac{m_a}{h}c^2 + \frac{1}{2}\frac{m_a}{h}v^2$
- $g_{a\gamma\gamma}$: Axion-photon coupling strength

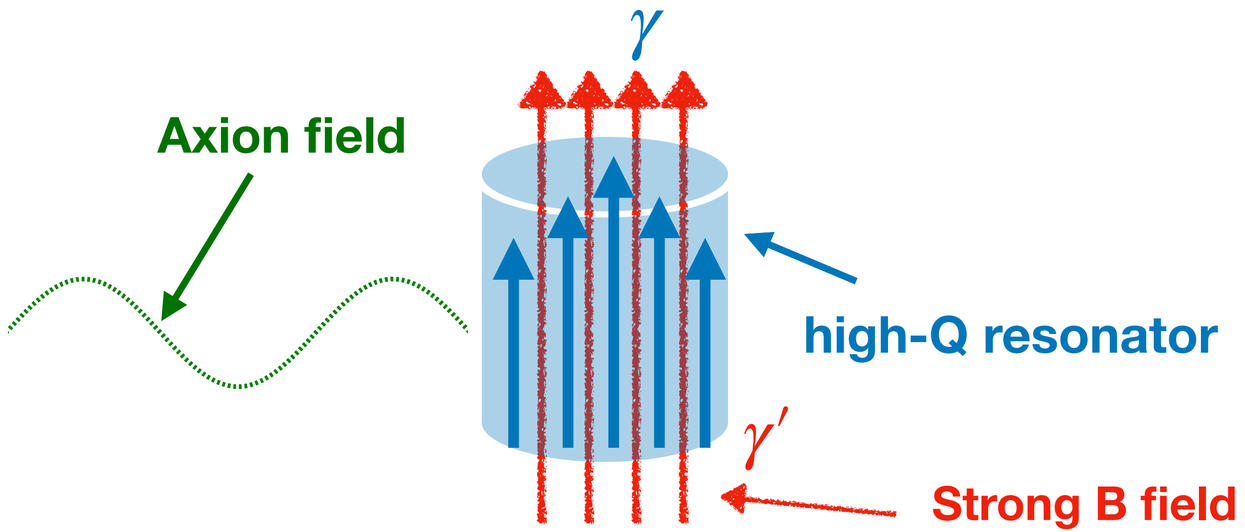


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

How to detect axions?

$$P_{\text{signal}} = g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} B_0^2 V C Q_L \frac{\beta}{1+\beta}$$

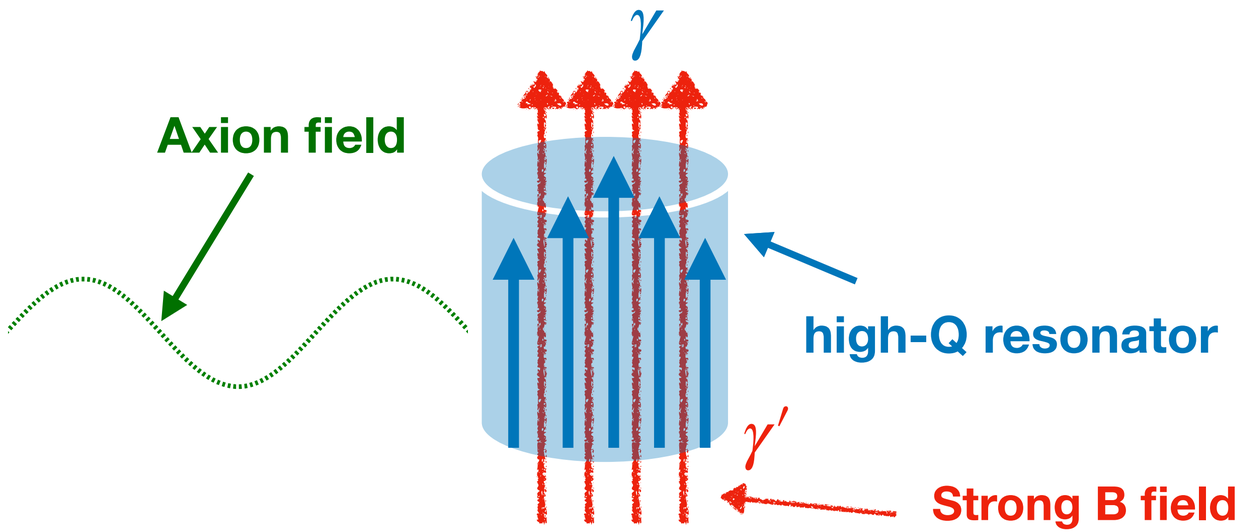
- Axion mass m_a determines the real photon frequency (f)
- $f = \frac{m_a}{h}c^2 + \frac{1}{2}\frac{m_a}{h}v^2$
- $g_{a\gamma\gamma}$: Axion-photon coupling strength
- C: Form factor $\propto \vec{E}_{cav} \cdot \vec{B}_{ext}$



How to detect axions?

$$P_{\text{signal}} = g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} B_0^2 V C Q_L \frac{\beta}{1+\beta}$$

- Axion mass m_a determines the real photon frequency (f)
- $f = \frac{m_a}{h}c^2 + \frac{1}{2}\frac{m_a}{h}v^2$
- $g_{a\gamma\gamma}$: Axion-photon coupling strength
- C: Form factor ∝ $\vec{E}_{cav} \cdot \vec{B}_{ext}$
- V: Cavity volume

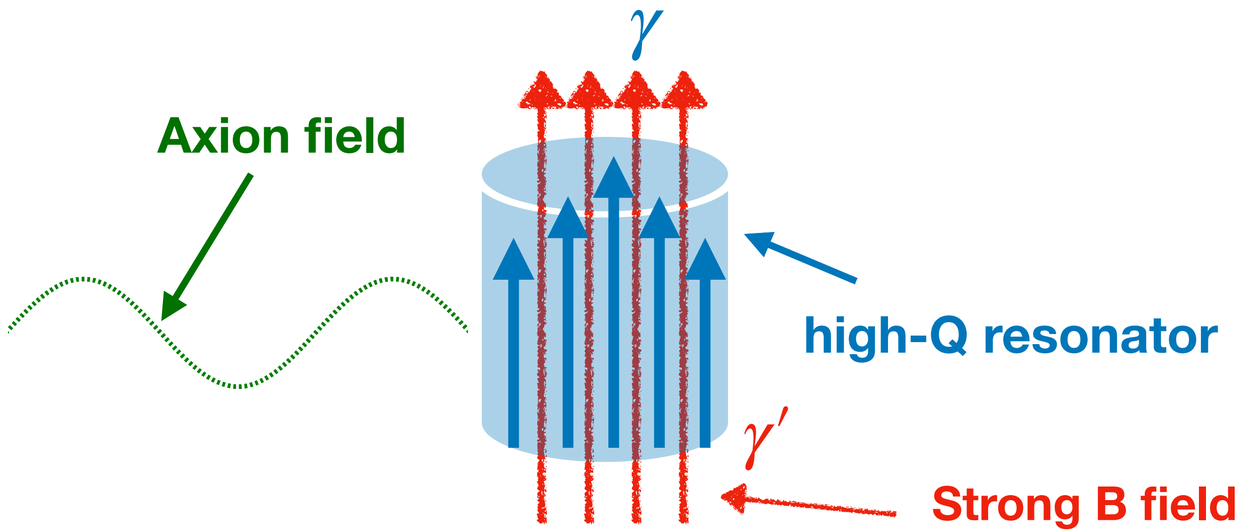


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

How to detect axions?

$$P_{\text{signal}} = g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} B_0^2 V C Q_L \frac{\beta}{1+\beta}$$

- Axion mass m_a determines the real photon frequency (f)
- $f = \frac{m_a}{h}c^2 + \frac{1}{2}\frac{m_a}{h}v^2$
- $g_{a\gamma\gamma}$: Axion-photon coupling strength
- C: Form factor ∝ $\vec{E}_{cav} \cdot \vec{B}_{ext}$
- V: Cavity volume
- Q_L: Cavity quality factor

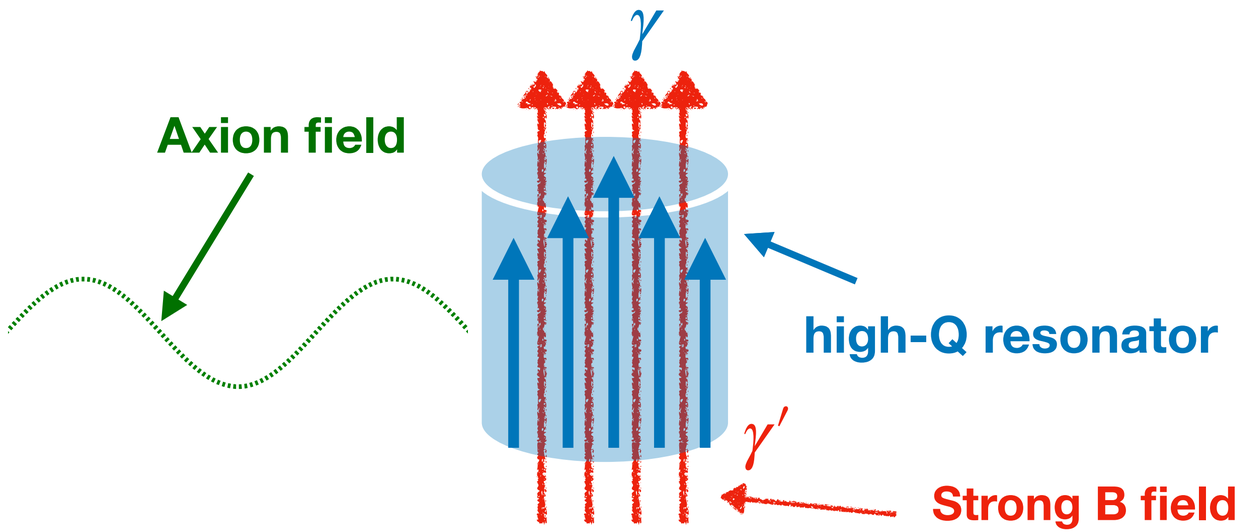


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

How to detect axions?

$$P_{\text{signal}} = g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} B_0^2 V C Q_L \frac{\beta}{1+\beta}$$

- Axion mass m_a determines the real photon frequency (f)
- $f = \frac{m_a}{h}c^2 + \frac{1}{2}\frac{m_a}{h}v^2$
- $g_{a\gamma\gamma}$: Axion-photon coupling strength
- C: Form factor $\propto \vec{E}_{cav} \cdot \vec{B}_{ext}$
- V: Cavity volume
- Q_L: Cavity quality factor
- β: Receiver coupling

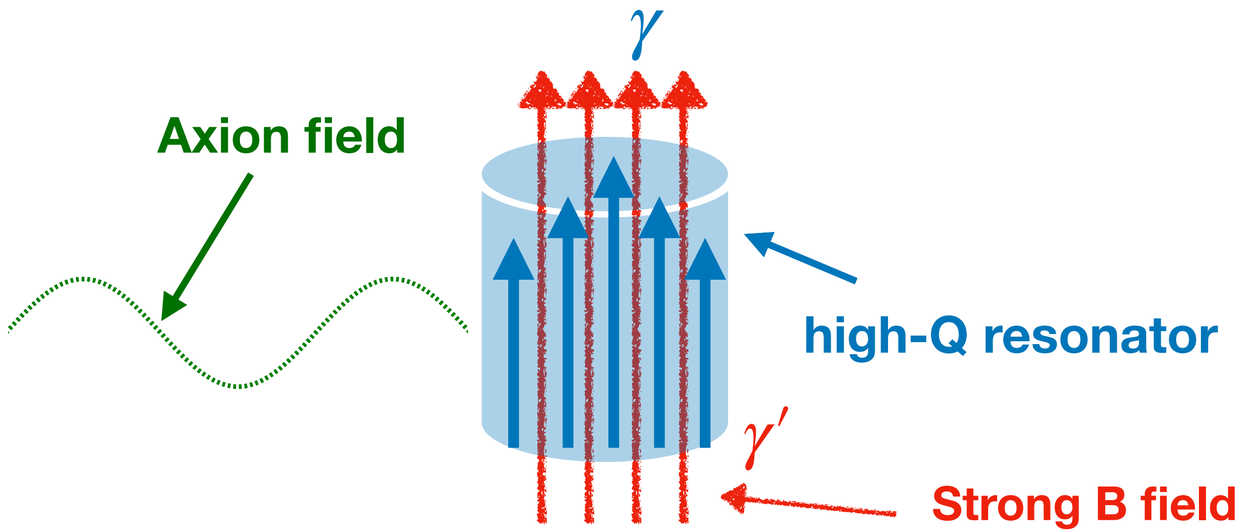


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

How to detect axions?

$$P_{\text{signal}} = g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} B_0^2 V C Q_L \frac{\beta}{1+\beta}$$

- Axion mass m_a determines the real photon frequency (f)
- $f = \frac{m_a}{h}c^2 + \frac{1}{2}\frac{m_a}{h}v^2$
- $g_{a\gamma\gamma}$: Axion-photon coupling strength
- C: Form factor ∝ $\vec{E}_{cav} \cdot \vec{B}_{ext}$
- V: Cavity volume
- Q_L: Cavity quality factor
- β: Receiver coupling
- B_0 : Magnetic field strength

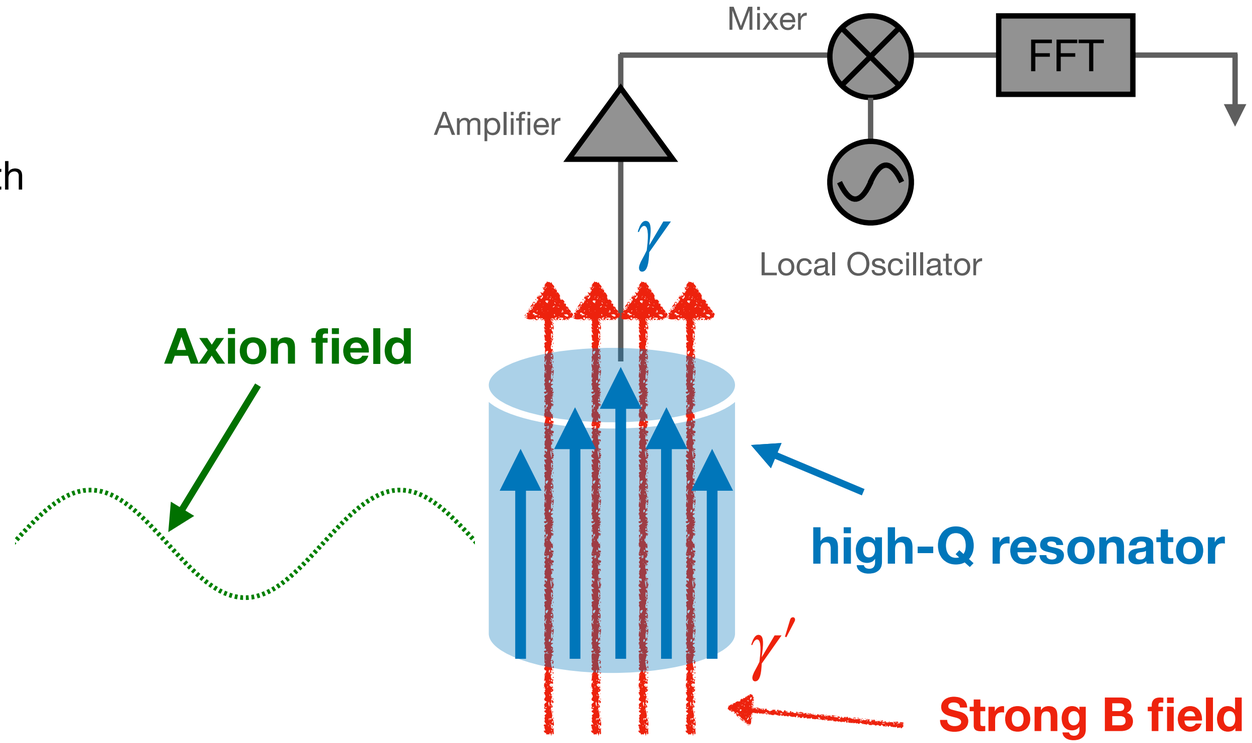


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

How to detect axions?

$$P_{\text{signal}} = g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} B_0^2 V C Q_L \frac{\beta}{1+\beta}$$

- Axion mass m_a determines the real photon frequency (f)
- $f = \frac{m_a}{h}c^2 + \frac{1}{2}\frac{m_a}{h}v^2$
- $g_{a\gamma\gamma}$: Axion-photon coupling strength
- C: Form factor $\propto \vec{E}_{cav} \cdot \vec{B}_{ext}$
- V: Cavity volume
- Q_L: Cavity quality factor
- β: Receiver coupling
- B_0 : Magnetic field strength

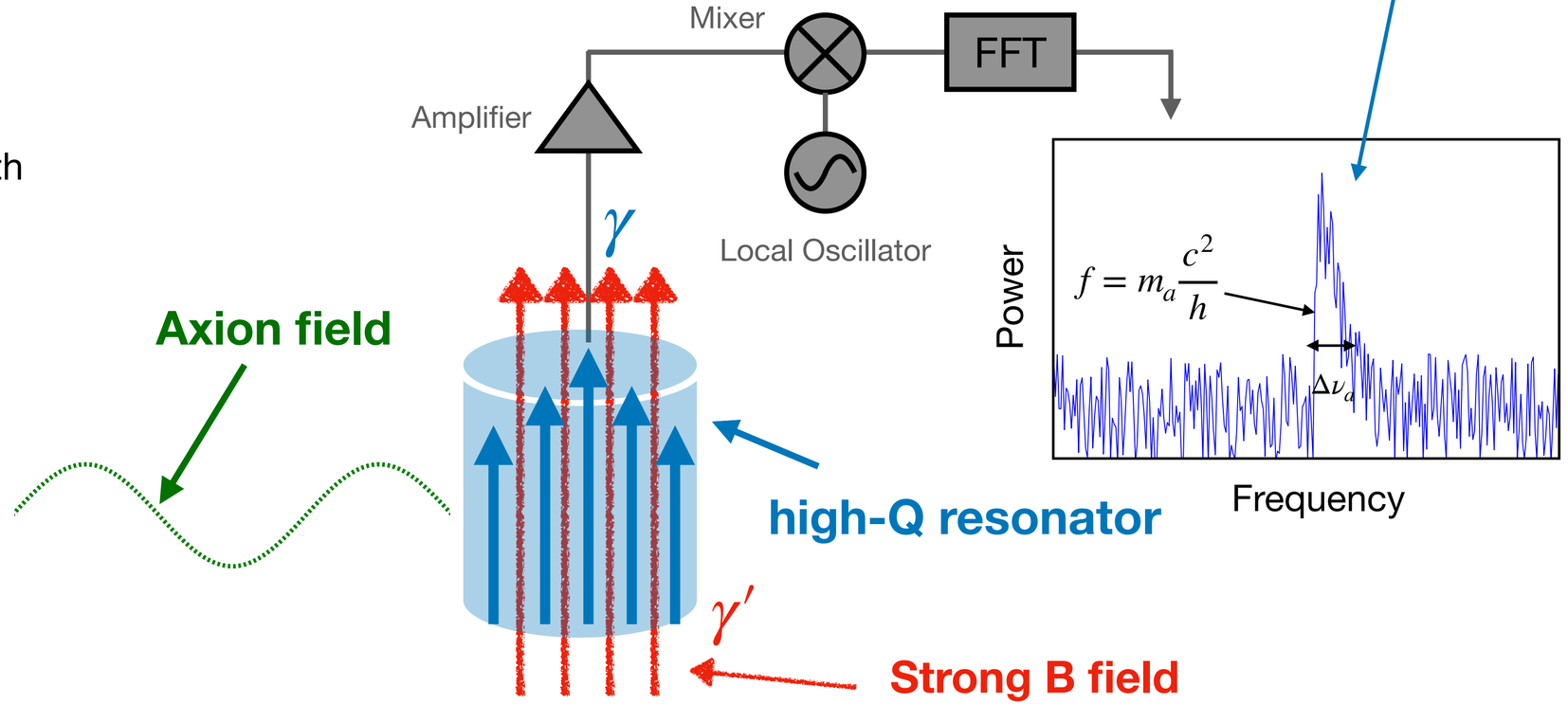


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

How to detect axions?

- Axion mass m_a determines the real photon frequency (f)
- $f = \frac{m_a}{h}c^2 + \frac{1}{2}\frac{m_a}{h}v^2$
- $g_{a\gamma\gamma}$: Axion-photon coupling strength
- C: Form factor $\propto \vec{E}_{cav} \cdot \vec{B}_{ext}$
- V: Cavity volume
- Q_L: Cavity quality factor
- β: Receiver coupling
- B_0 : Magnetic field strength

$$P_{\text{signal}} = g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} B_0^2 V C Q_L \frac{\beta}{1+\beta}$$



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

How to detect axions?

How to detect axions?

- $P_{\text{signal}} \approx \mathcal{O}(10^{-26})\, W$

How to detect axions?

- $P_{\text{signal}} \approx \mathcal{O}(10^{-26})\, W$
- We must resolve this tiny signal above the noise of our experiment

How to detect axions?

- $P_{\text{signal}} \approx \mathcal{O}(10^{-26})\, W$
- We must resolve this tiny signal above the noise of our experiment
- $$\text{SNR} = \frac{P_{\text{signal}}}{k_{\text{B}} T_{\text{S}}} \sqrt{\frac{\tau}{\Delta \nu_{\text{a}}}}$$

How to detect axions?

- $P_{\text{signal}} \approx \mathcal{O}(10^{-26})\, W$
- We must resolve this tiny signal above the noise of our experiment
- $$\text{SNR} = \frac{P_{\text{signal}}}{k_{\text{B}} T_{\text{S}}} \sqrt{\frac{\tau}{\Delta \nu_{\text{a}}}}$$
- **Scan rate** - How fast we can exclude axions at a given **mass** and **coupling**

How to detect axions?

- $P_{\text{signal}} \approx \mathcal{O}(10^{-26})\, W$
- We must resolve this tiny signal above the noise of our experiment
- $$\text{SNR} = \frac{P_{\text{signal}}}{k_{\text{B}} T_{\text{S}}} \sqrt{\frac{\tau}{\Delta \nu_{\text{a}}}}$$
- **Scan rate** - How fast we can exclude axions at a given **mass** and **coupling**
- $$\frac{df}{dt} = \left(\frac{g_{\text{a}\gamma\gamma}^4 \rho_{\text{a}}^2 Q_{\text{a}}}{m_{\text{a}}^2 k_{\text{B}}^2} \right) \frac{B_0^4}{\text{SNR}^2\, T_S^2} C^2 V^2 Q_{\text{L}} \frac{\beta^2}{(1+\beta)^2}$$

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

How to detect axions?

- $P_{\text{signal}} \approx \mathcal{O}(10^{-26})\, W$
- We must resolve this tiny signal above the noise of our experiment
- $$\text{SNR} = \frac{P_{\text{signal}}}{k_{\text{B}} T_{\text{S}}} \sqrt{\frac{\tau}{\Delta \nu_{\text{a}}}}$$
- **Scan rate** - How fast we can exclude axions at a given **mass** and **coupling**
- $$\frac{df}{dt} = \left(\frac{g_{\text{a}\gamma\gamma}^4 \rho_{\text{a}}^2 Q_{\text{a}}}{m_{\text{a}}^2 k_{\text{B}}^2} \right) \frac{B_0^4}{\text{SNR}^2\, T_S^2} C^2 V^2 Q_{\text{L}} \frac{\beta^2}{(1+\beta)^2}$$

Determined by nature

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

How to detect axions?

- $P_{\text{signal}} \approx \mathcal{O}(10^{-26})\, W$
- We must resolve this tiny signal above the noise of our experiment
- $$\text{SNR} = \frac{P_{\text{signal}}}{k_{\text{B}} T_{\text{S}}} \sqrt{\frac{\tau}{\Delta \nu_{\text{a}}}}$$
- **Scan rate** - How fast we can exclude axions at a given **mass** and **coupling**
- $$\frac{df}{dt} = \left(\frac{g_{\text{a}\gamma\gamma}^4 \rho_{\text{a}}^2 Q_{\text{a}}}{m_{\text{a}}^2 k_{\text{B}}^2} \right) \frac{B_0^4}{\text{SNR}^2\, T_S^2} C^2 V^2 Q_{\text{L}} \frac{\beta^2}{(1+\beta)^2}$$

Determined by nature Experiment dependent

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

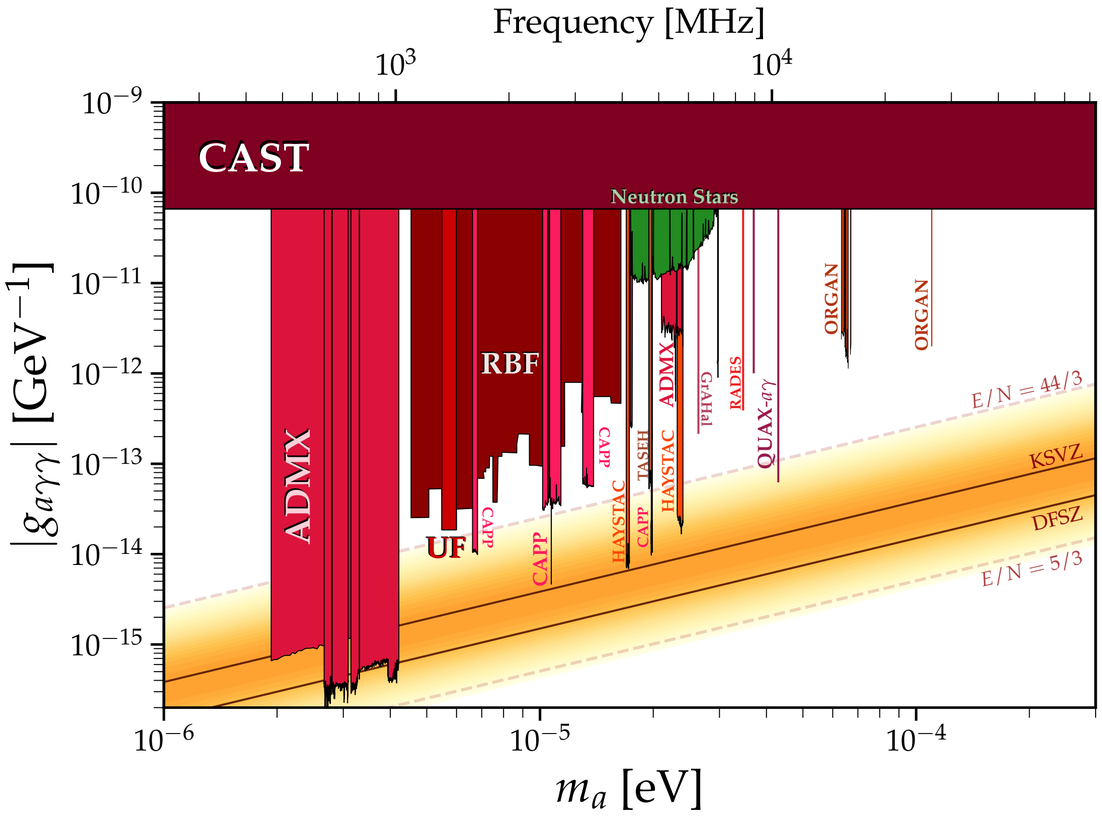
How to detect axions?

- $P_{\text{signal}} \approx \mathcal{O}(10^{-26})\, W$
- We must resolve this tiny signal above the noise of our experiment
- $$\text{SNR} = \frac{P_{\text{signal}}}{k_B T_S} \sqrt{\frac{\tau}{\Delta \nu_a}}$$
- **Scan rate** - How fast we can exclude axions at a given **mass** and **coupling**
- $$\frac{df}{dt} = \left(\frac{g_{a\gamma\gamma}^4 \rho_a^2 Q_a}{m_a^2 k_B^2} \right) \frac{B_0^4}{\text{SNR}^2 T_S^2} C^2 V^2 Q_L \frac{\beta^2}{(1+\beta)^2}$$

Determined by nature | Experiment dependent | Cavity dependent

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ORGAN: **O**scillating **R**esonant **G**roup **A**xio**N** Experiment

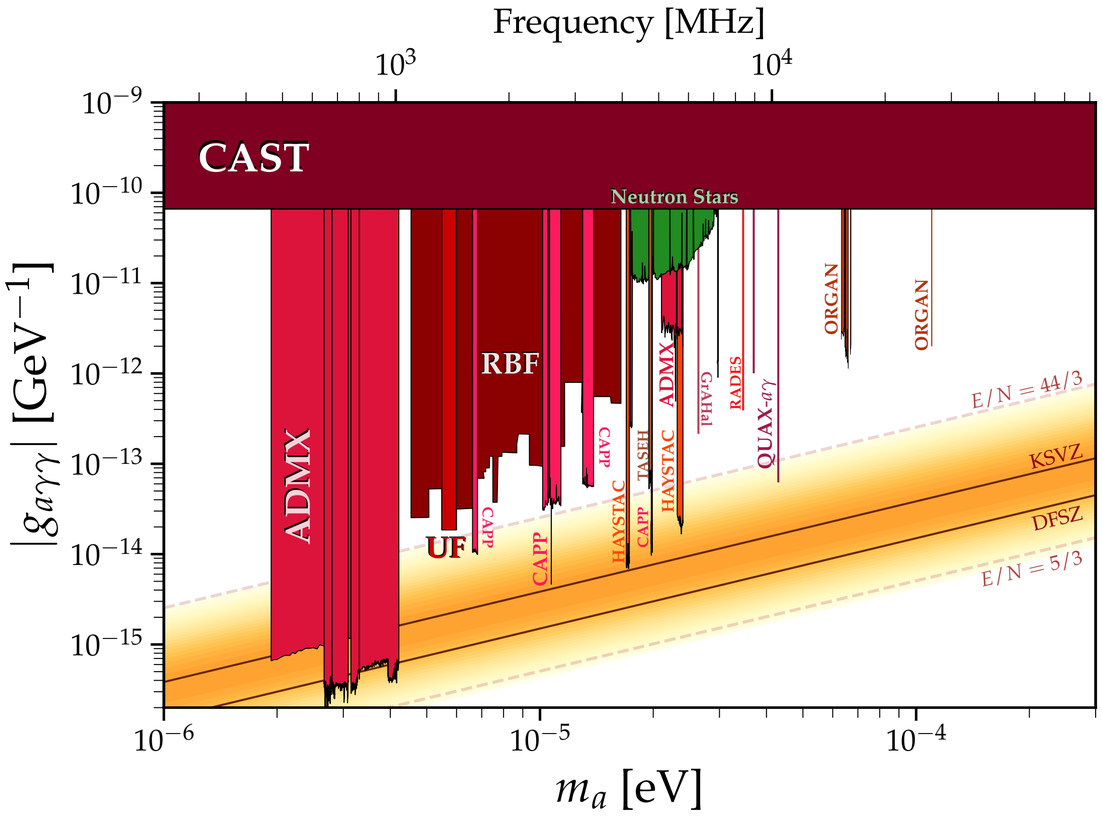


cajohare.github.io/AxionLimits

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ORGAN: **O**scillating **R**esonant **G**roup **A**xio**N** Experiment

- High frequency (>15 GHz) axion haloscope hosted at UWA

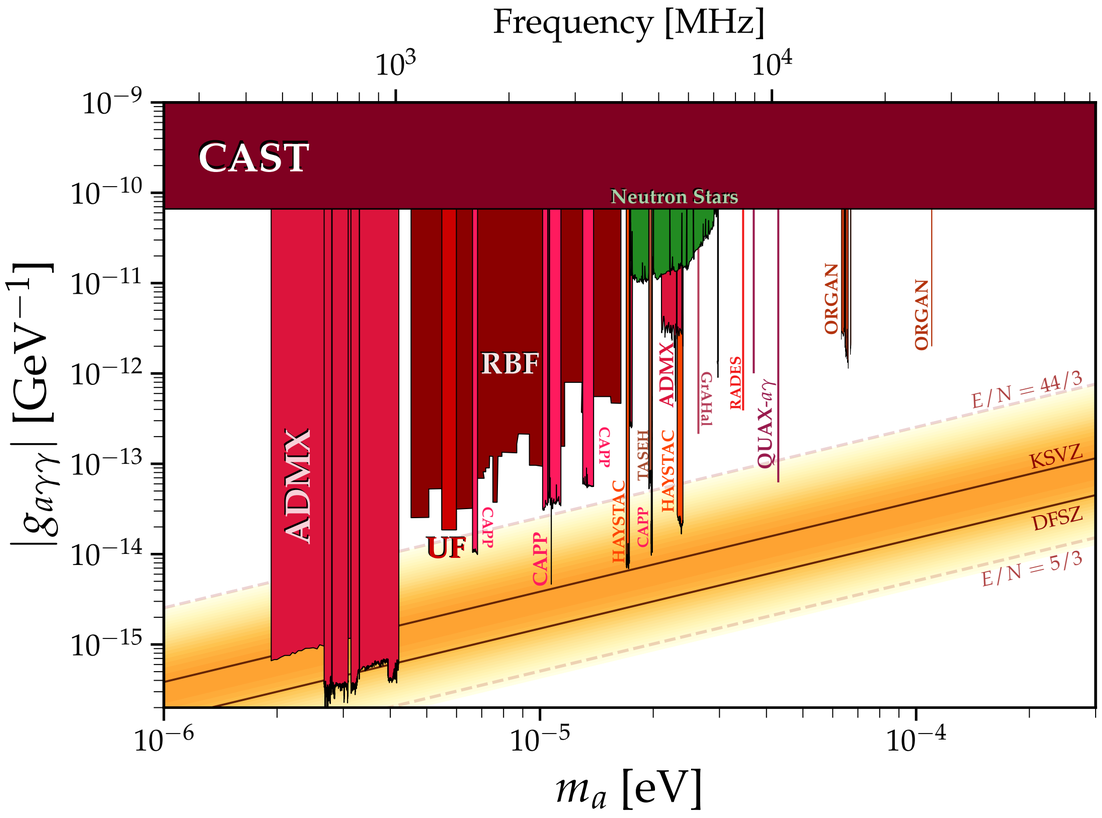


cajohare.github.io/AxionLimits

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ORGAN: **O**scillating **R**esonant **G**roup **A**xio**N** Experiment

- High frequency (>15 GHz) axion haloscope hosted at UWA
- **Why high frequency?**

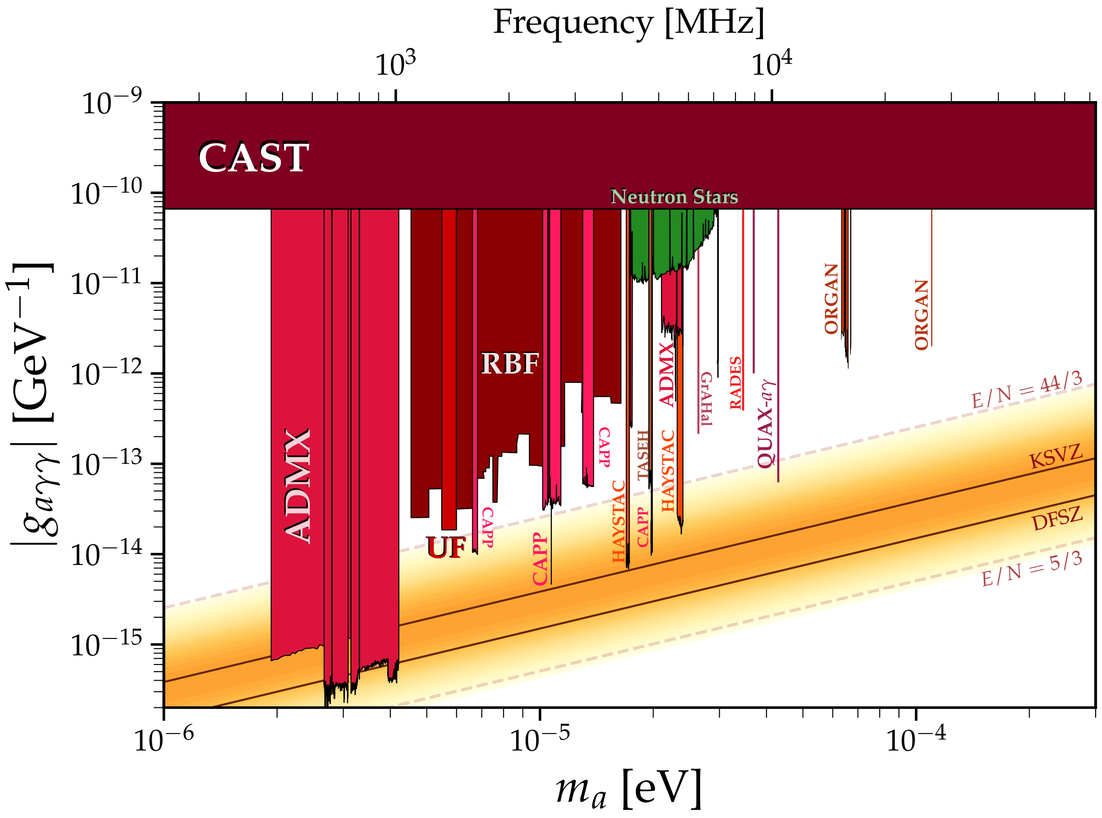


cajohare.github.io/AxionLimits

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ORGAN: **O**scillating **R**esonant **G**roup **A**xio**N** Experiment

- High frequency (>15 GHz) axion haloscope hosted at UWA
- **Why high frequency?**
- The high frequency parameter space is largely unexplored

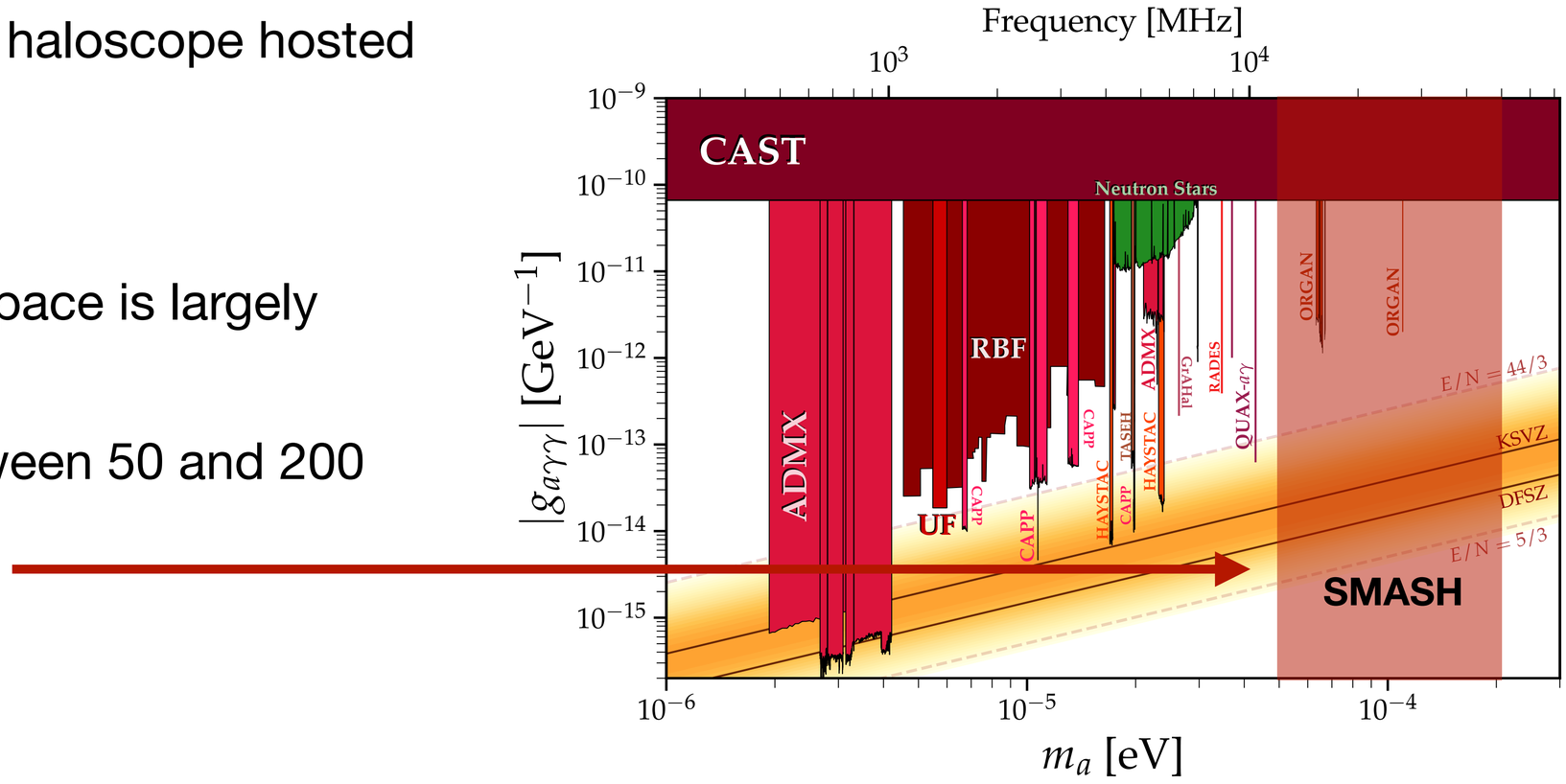


cajohare.github.io/AxionLimits

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ORGAN: **O**scillating **R**esonant **G**roup **A**xio**N** Experiment

- High frequency (>15 GHz) axion haloscope hosted at UWA
- **Why high frequency?**
- The high frequency parameter space is largely unexplored
- **SMASH** model predicts m_a between 50 and 200 μeV

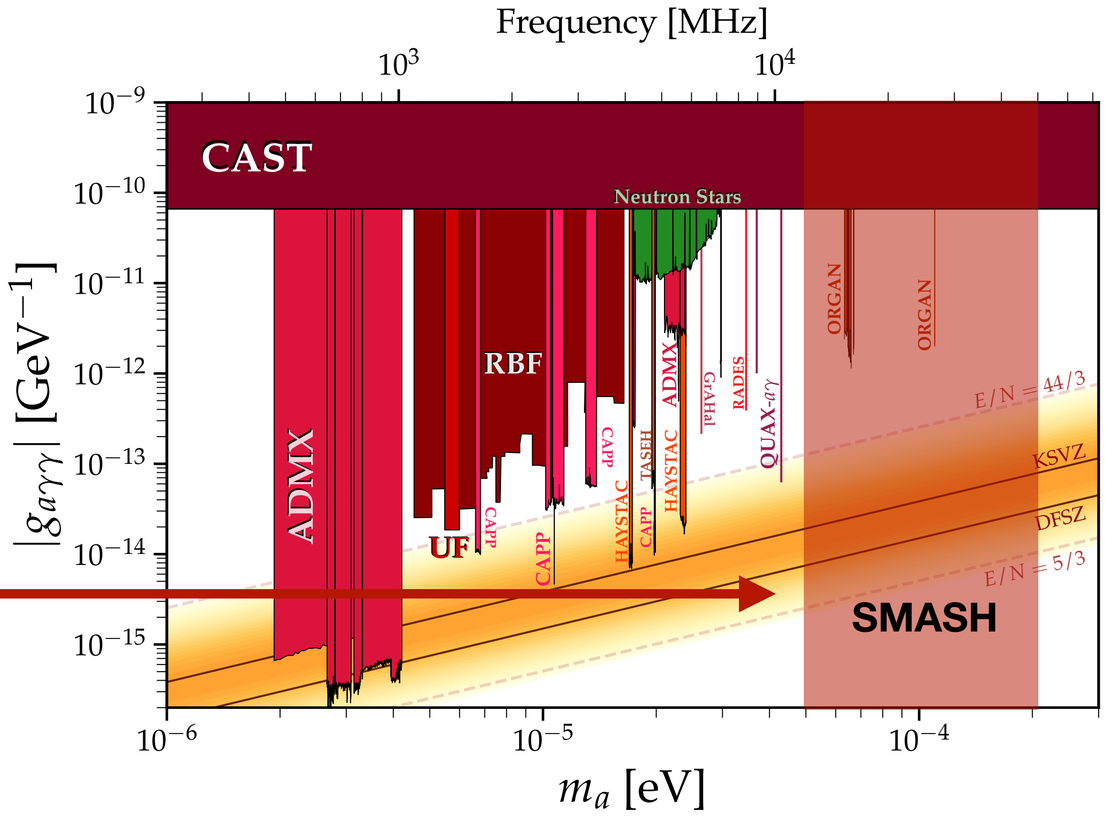


cajohare.github.io/AxionLimits

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ORGAN: **O**scillating **R**esonant **G**roup **A**xio**N** Experiment

- High frequency (>15 GHz) axion haloscope hosted at UWA
- **Why high frequency?**
- The high frequency parameter space is largely unexplored
- **SMASH** model predicts m_a between 50 and 200 μeV
- QCD lattice simulations favour $40 \leq m_a \leq 180\,\mu eV$

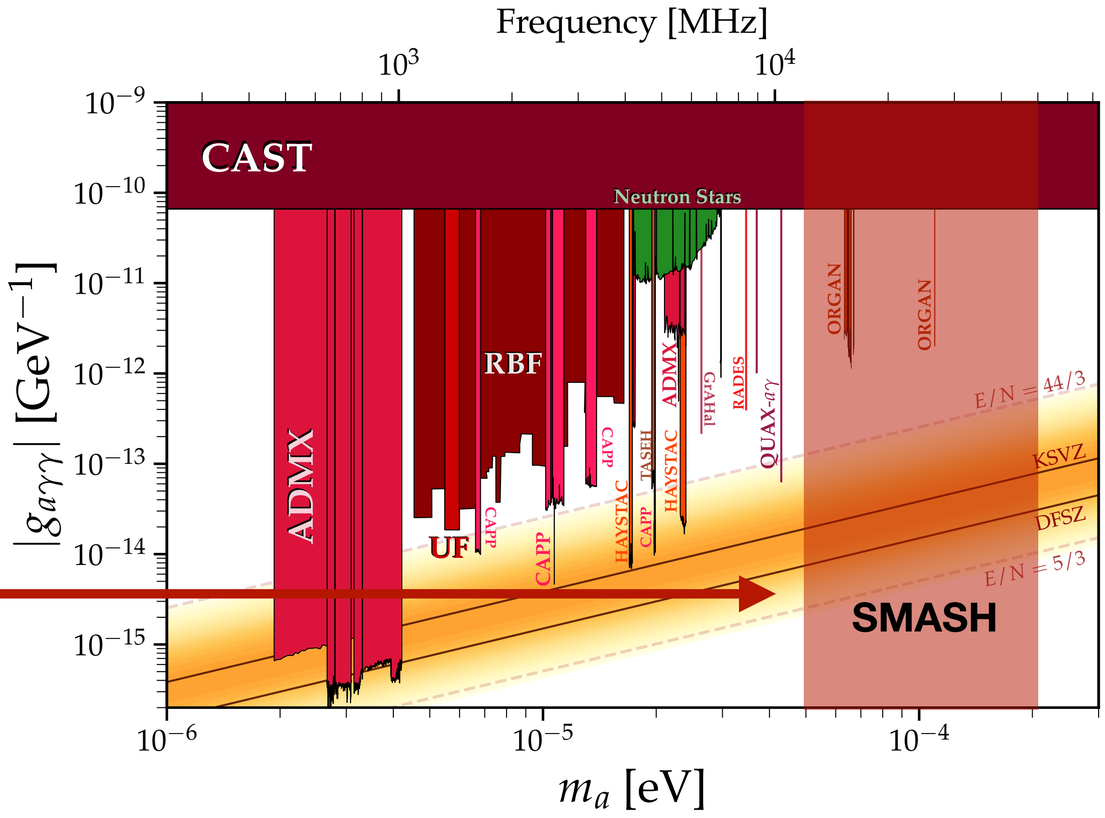


cajohare.github.io/AxionLimits

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ORGAN: **O**scillating **R**esonant **G**roup **A**xio**N** Experiment

- High frequency (>15 GHz) axion haloscope hosted at UWA
- **Why high frequency?**
- The high frequency parameter space is largely unexplored
- **SMASH** model predicts m_a between 50 and 200 μeV
- QCD lattice simulations favour $40 \leq m_a \leq 180\,\mu eV$
- $\frac{df}{dt} \propto f^{-14/3} \rightarrow$ High frequency scans are hard

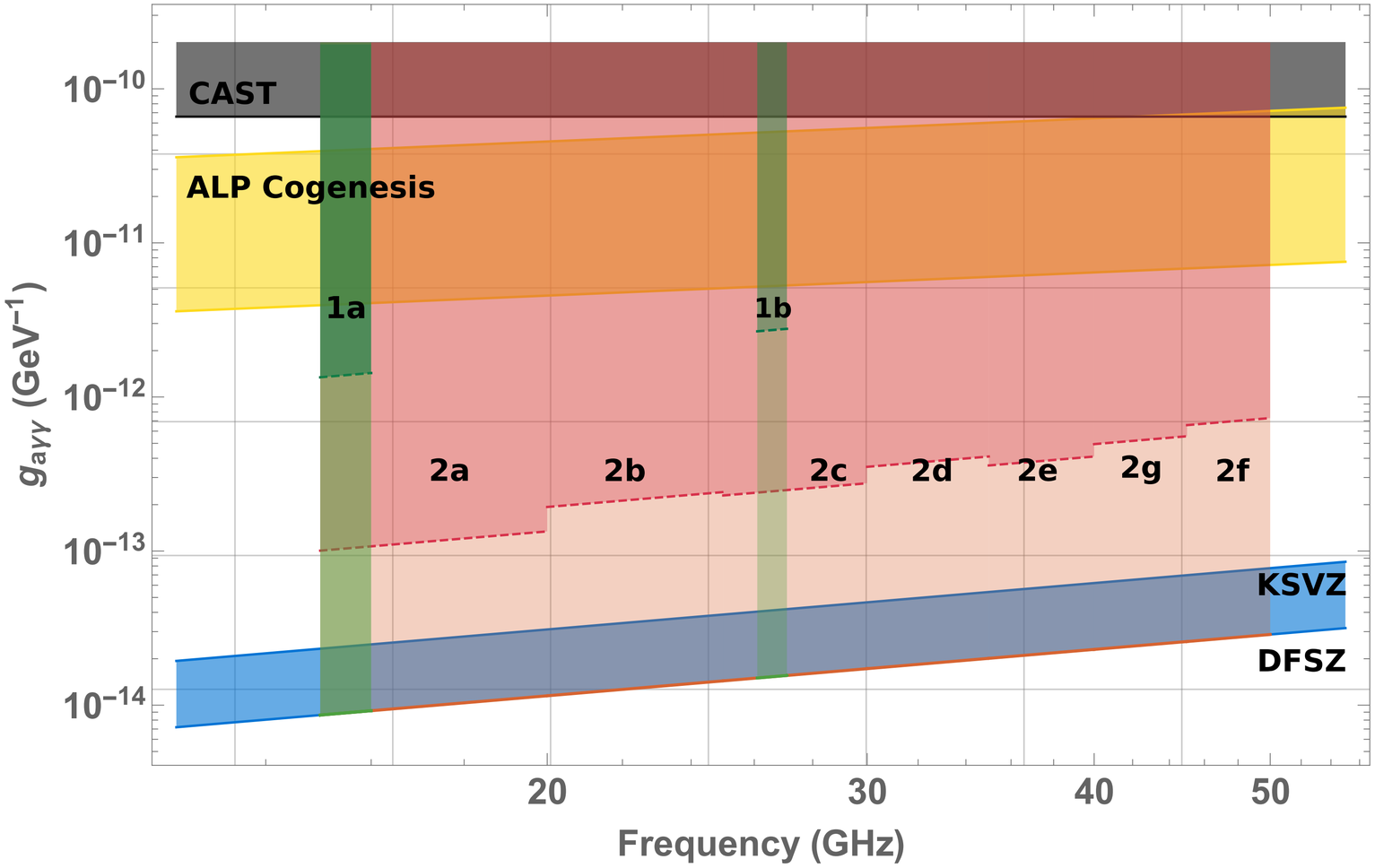


cajohare.github.io/AxionLimits

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ORGAN Run Plan

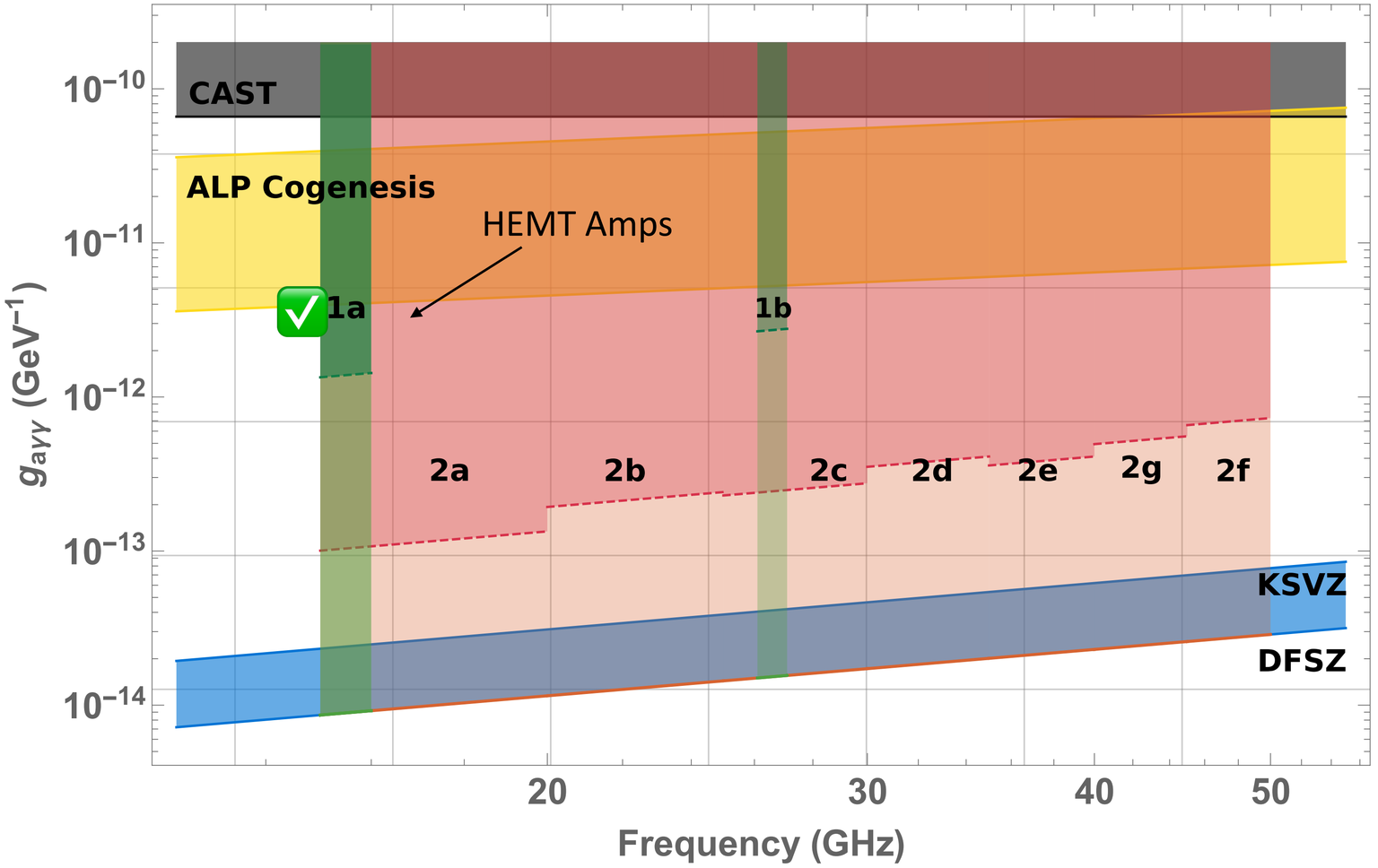
ORGAN Run Plan



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ORGAN Run Plan

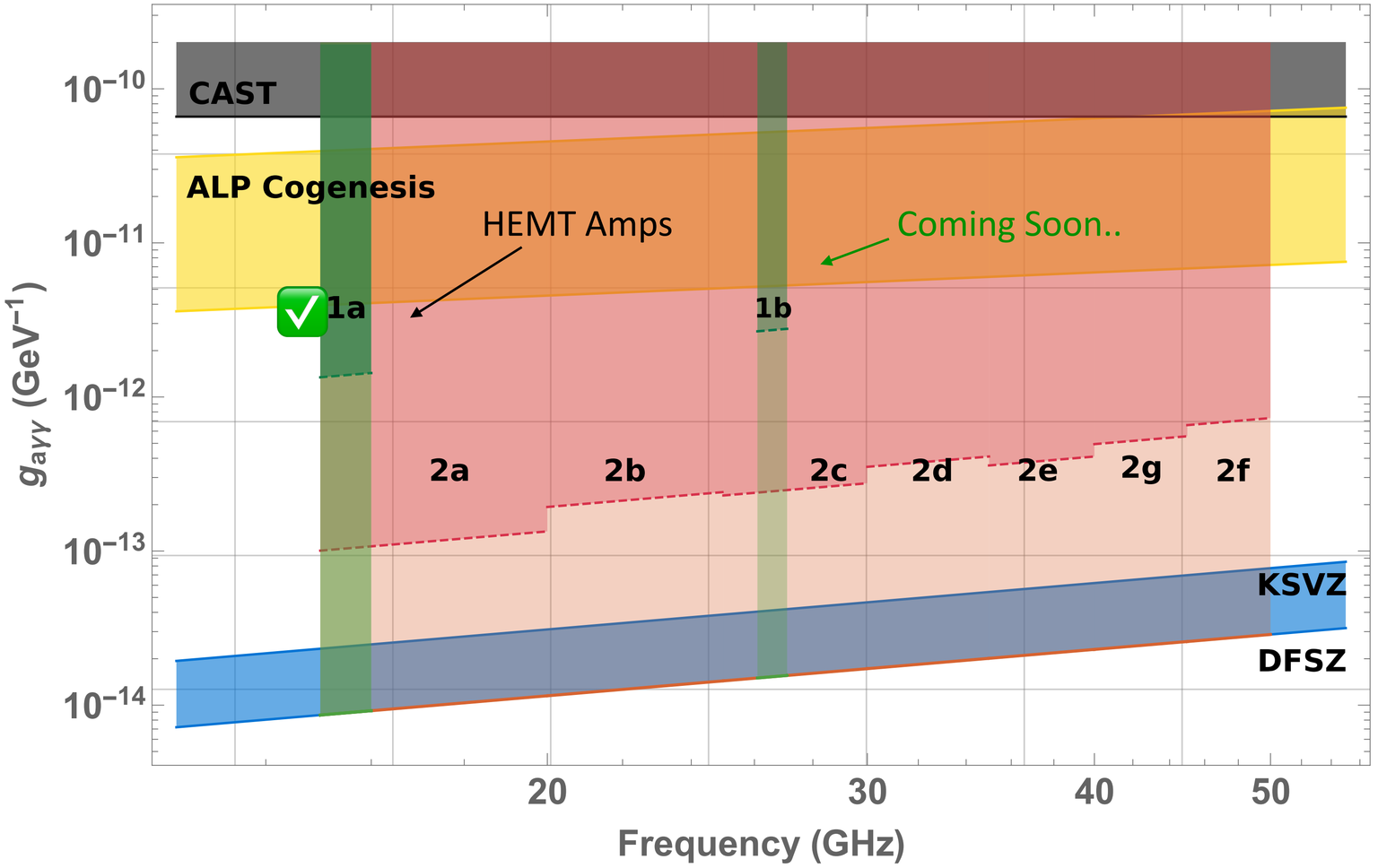
- Phase 1: Targeted searches around 15-16 GHz and 26-27 GHz ~month scale



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ORGAN Run Plan

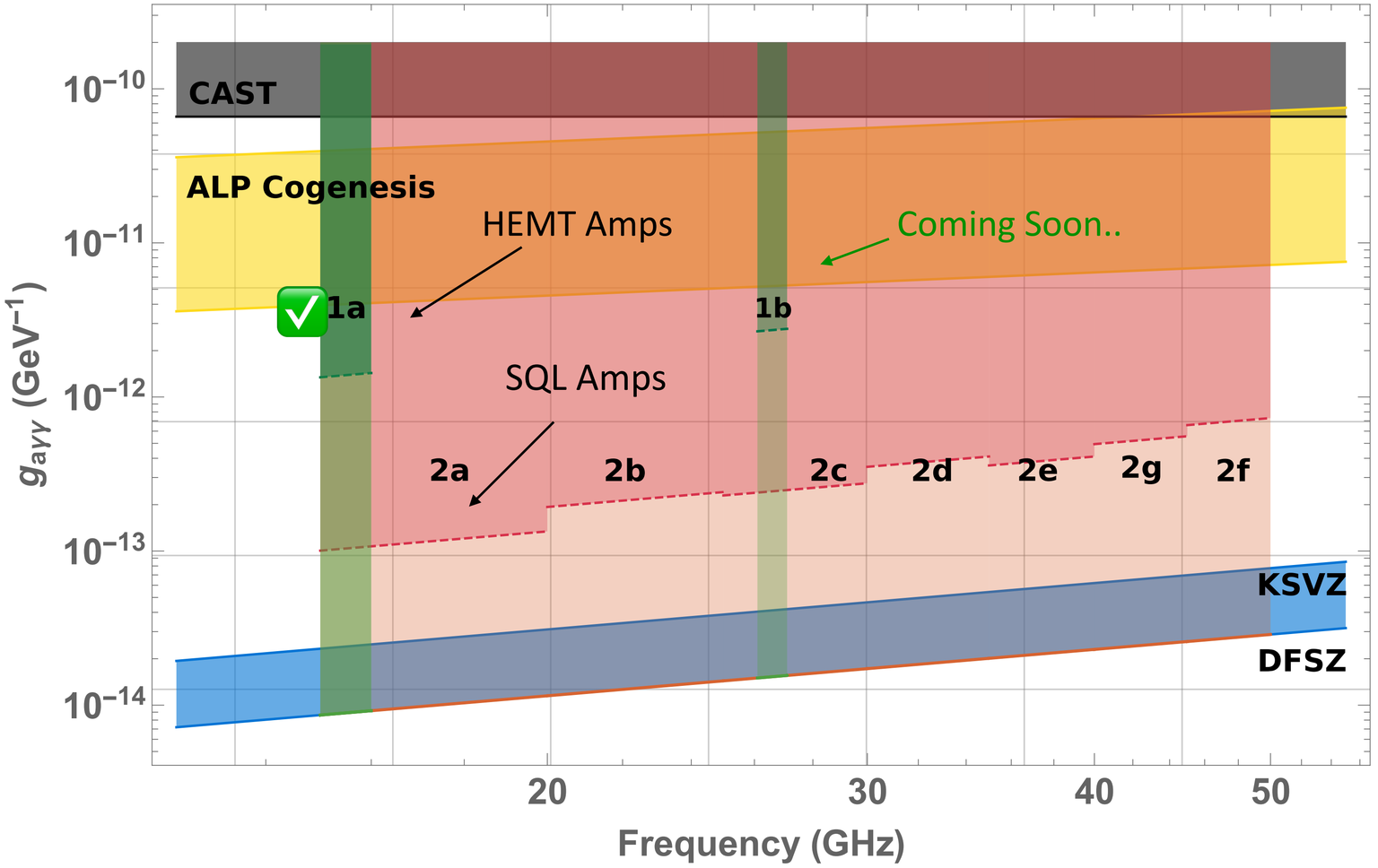
- Phase 1: Targeted searches around 15-16 GHz and 26-27 GHz ~month scale



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ORGAN Run Plan

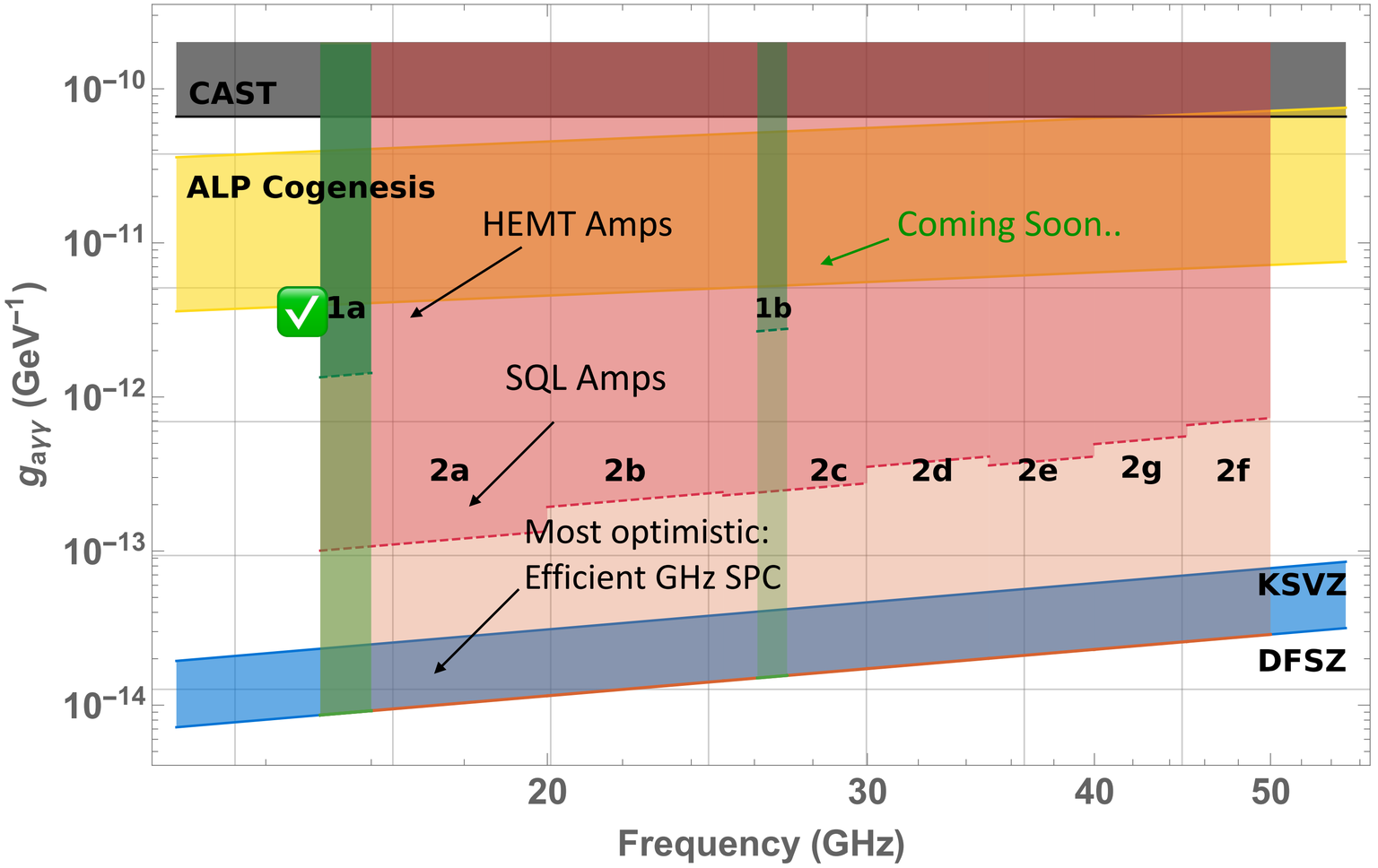
- Phase 1: Targeted searches around 15-16 GHz and 26-27 GHz ~month scale
- Phase 2: Wider searches (15-50GHz) building on expertise gained in Phase 1 ~ year scale



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ORGAN Run Plan

- Phase 1: Targeted searches around 15-16 GHz and 26-27 GHz ~month scale
- Phase 2: Wider searches (15-50GHz) building on expertise gained in Phase 1 ~ year scale



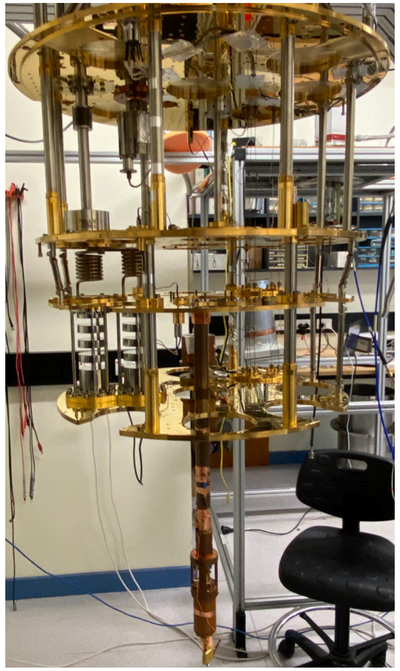
ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a

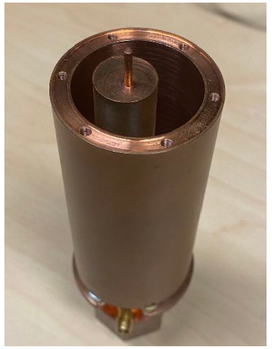
ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a

Dilution fridge



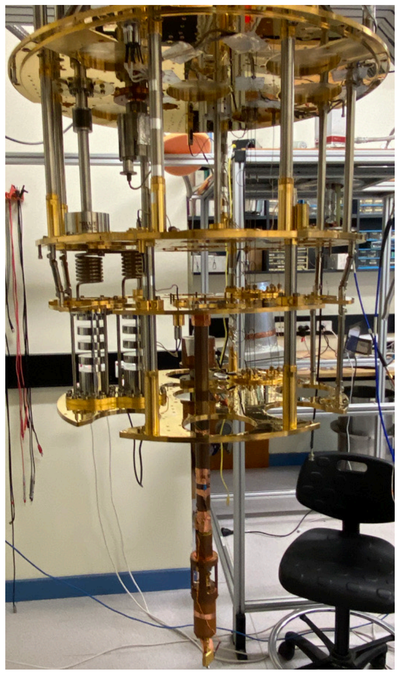
Rotation stage

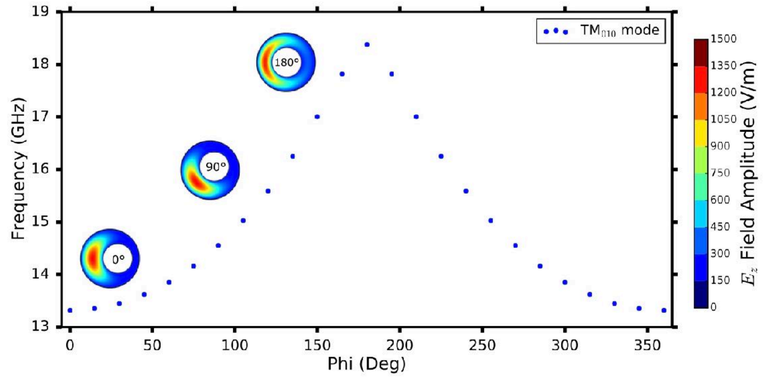


Phase 1a

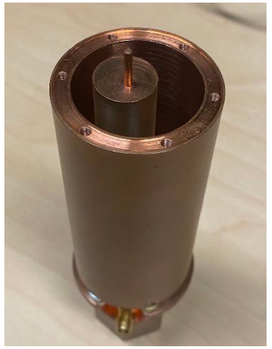
By **moving the rod radially** the mode is perturbed, shifting the frequency

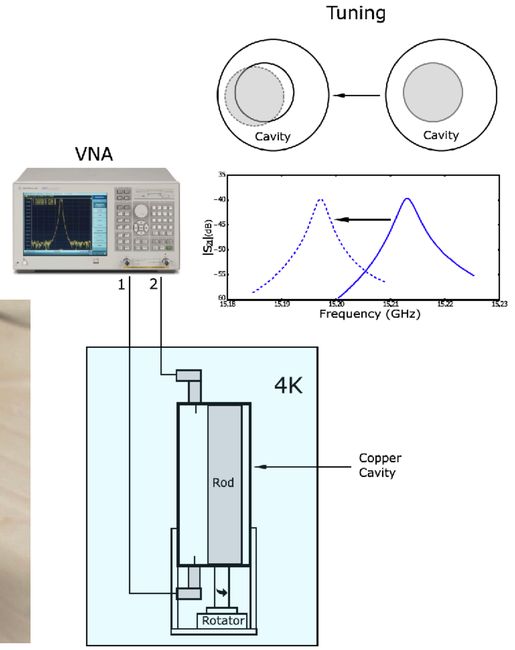
Dilution fridge





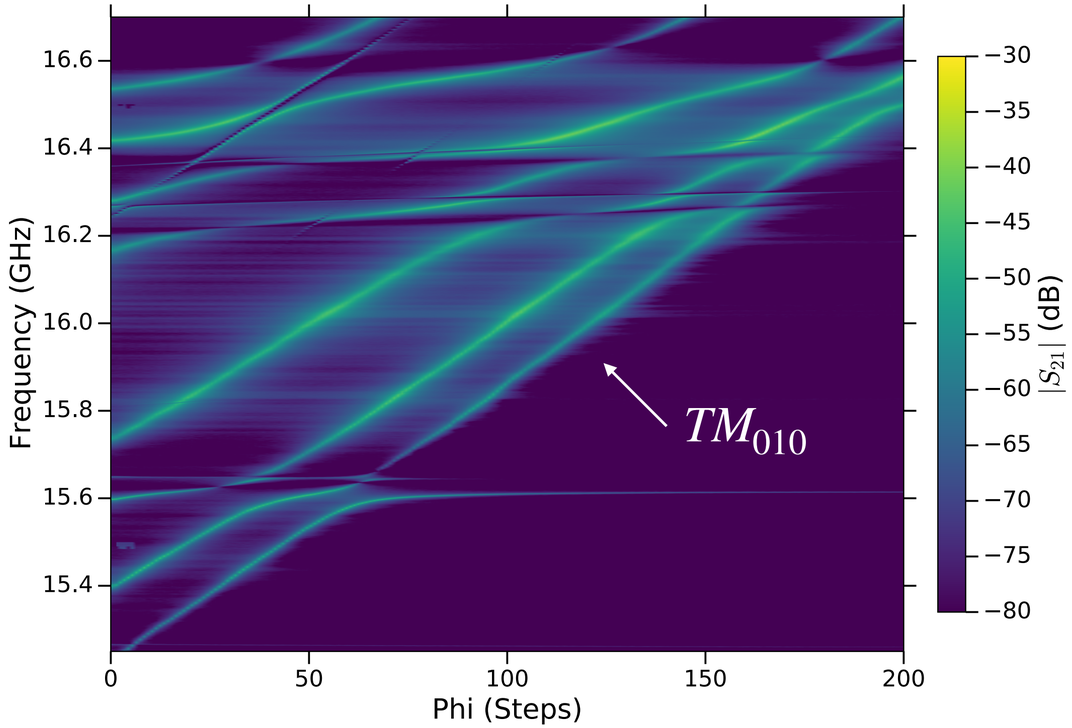
Rotation stage



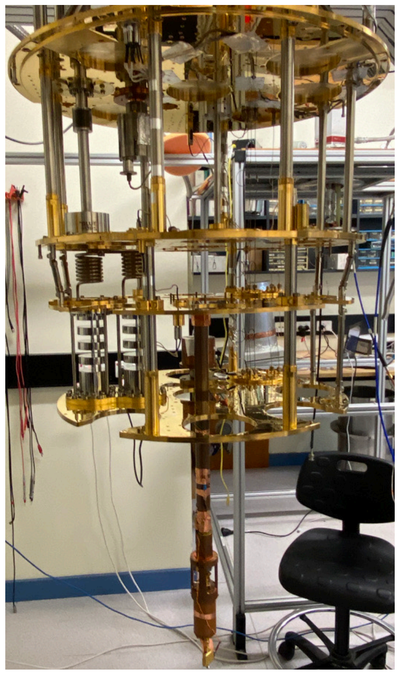


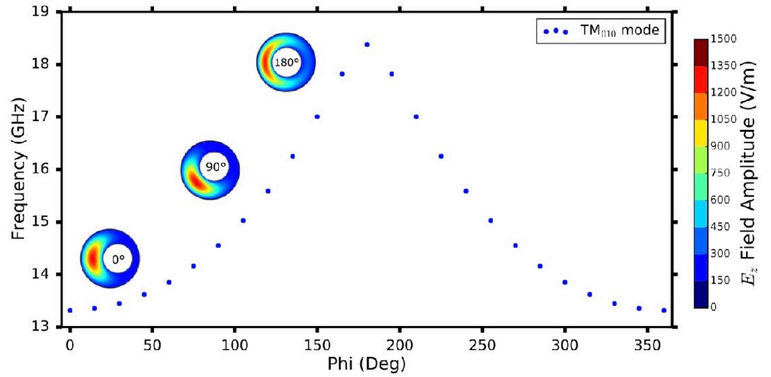
Phase 1a

By **moving the rod radially** the mode is perturbed, shifting the frequency

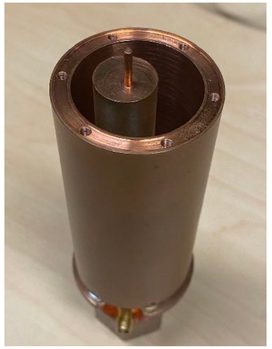


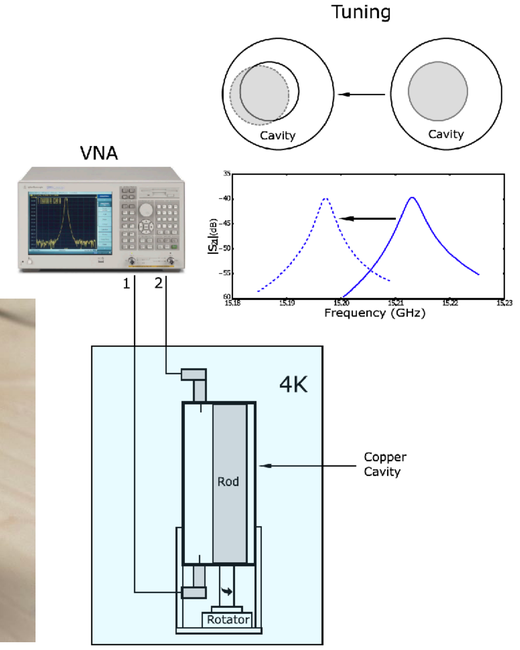
Dilution fridge





Rotation stage

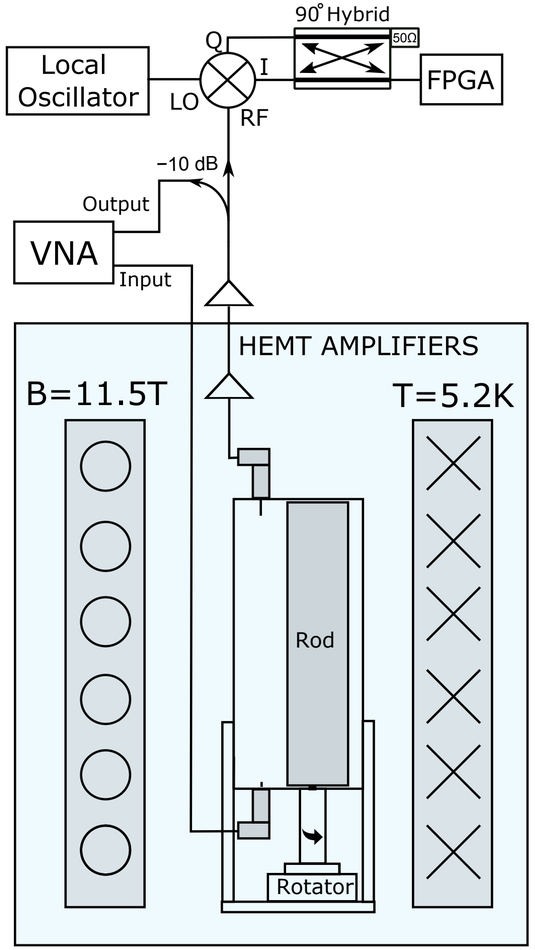




Phase 1a

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

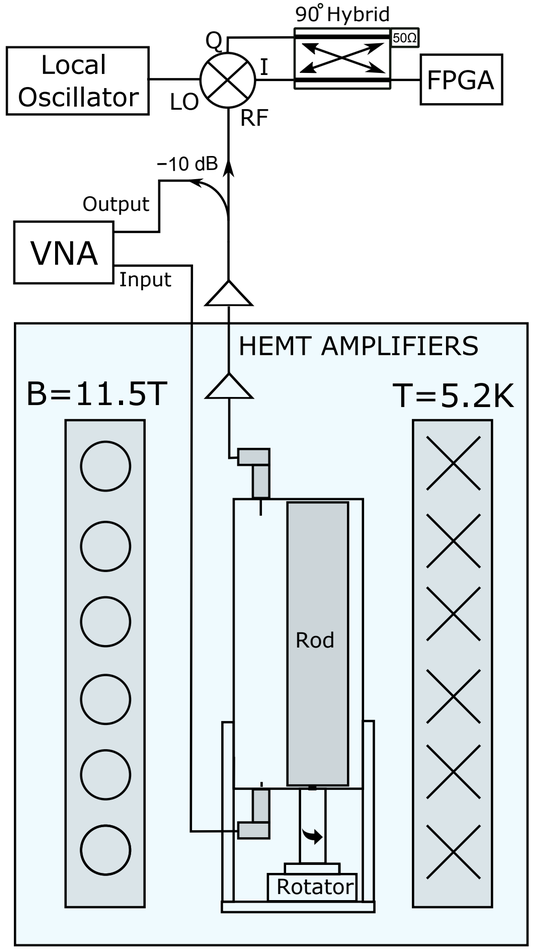
Phase 1a



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a

Step motor



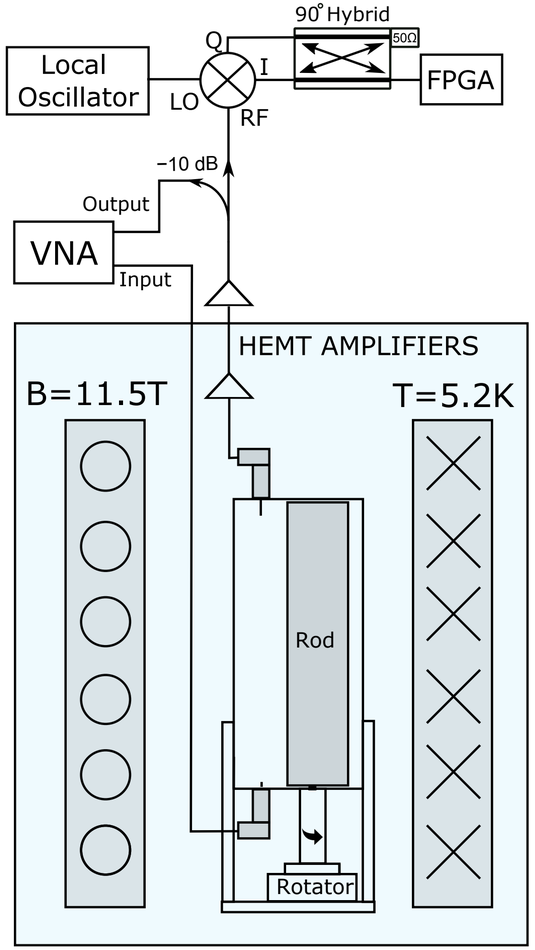
ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a

Step motor

↓

Sweep VNA for Q and f_c



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a

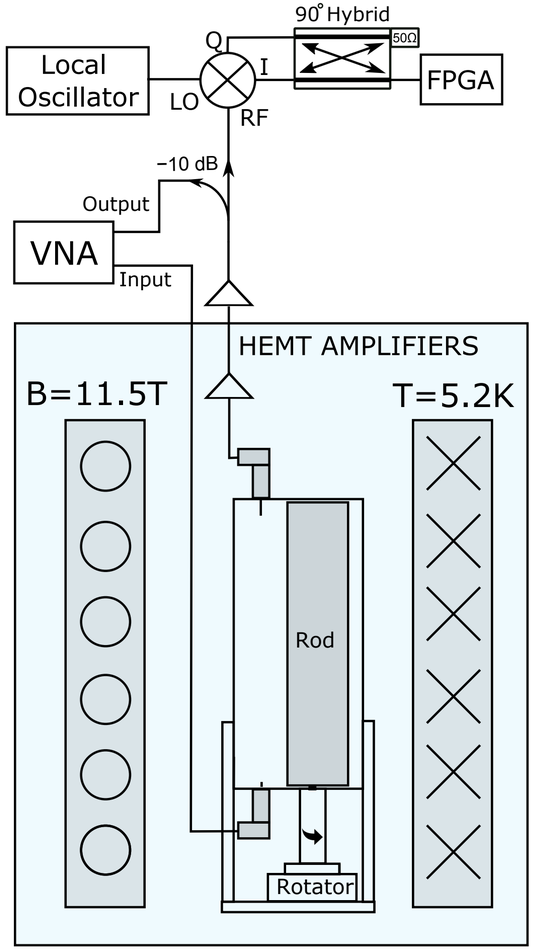
Step motor

↓

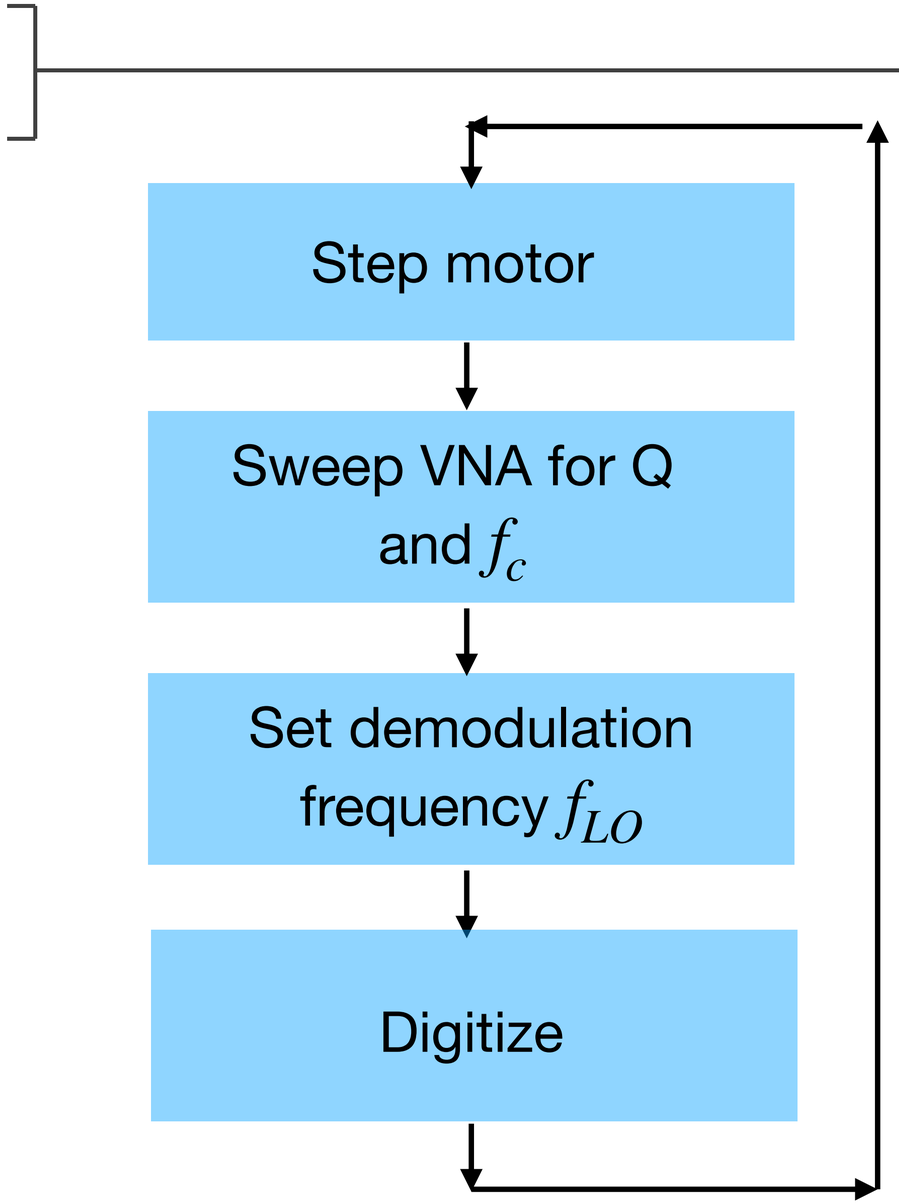
Sweep VNA for Q and f_c

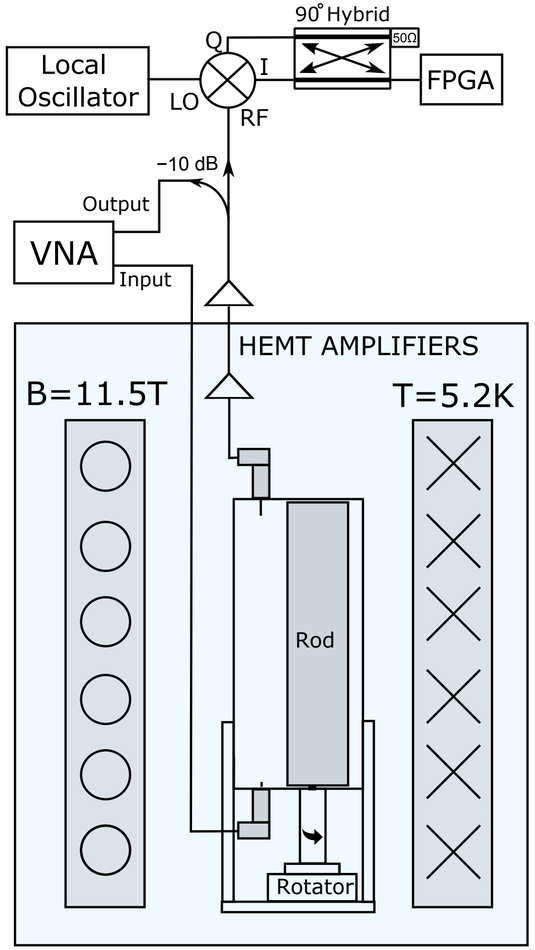
↓

Set demodulation frequency f_{LO}



Phase 1a

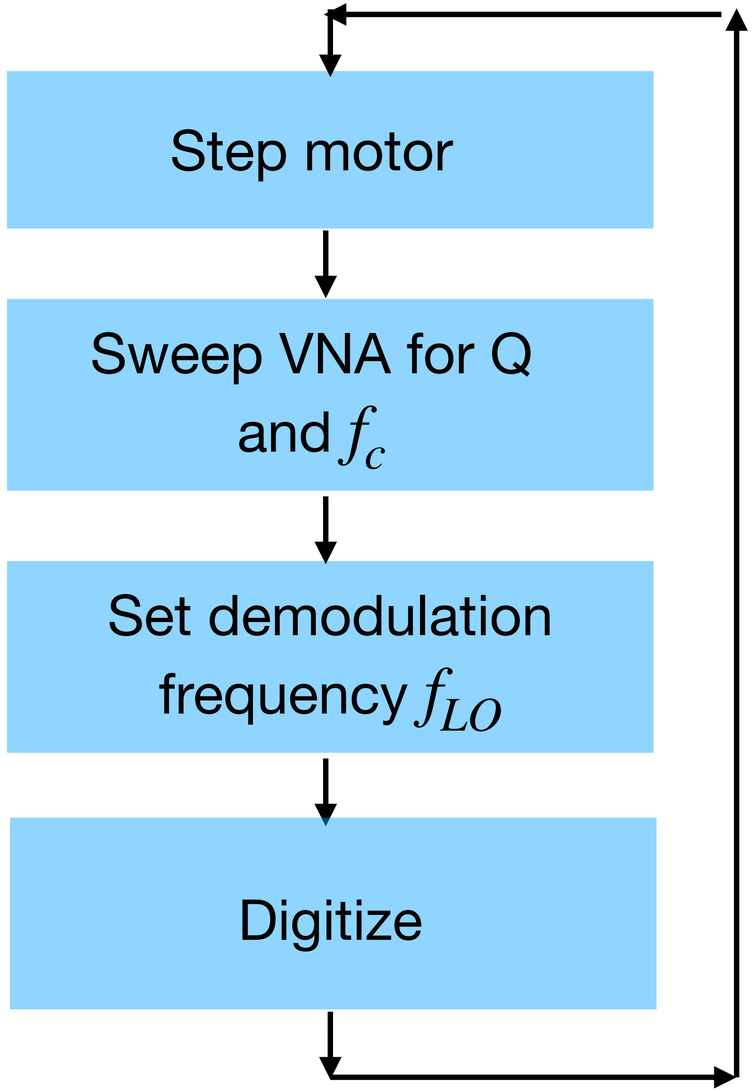


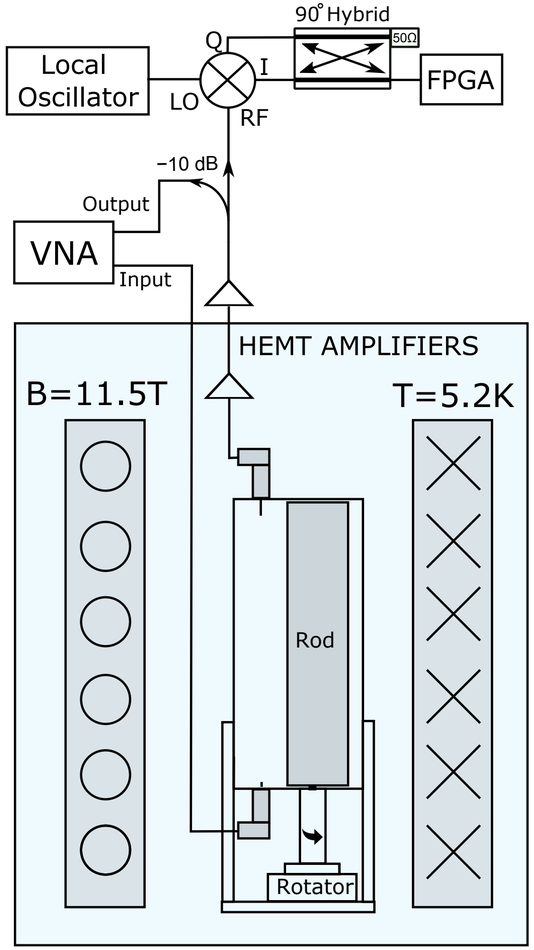


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a

- We scanned for ~ 3.5 weeks (~700MHz)

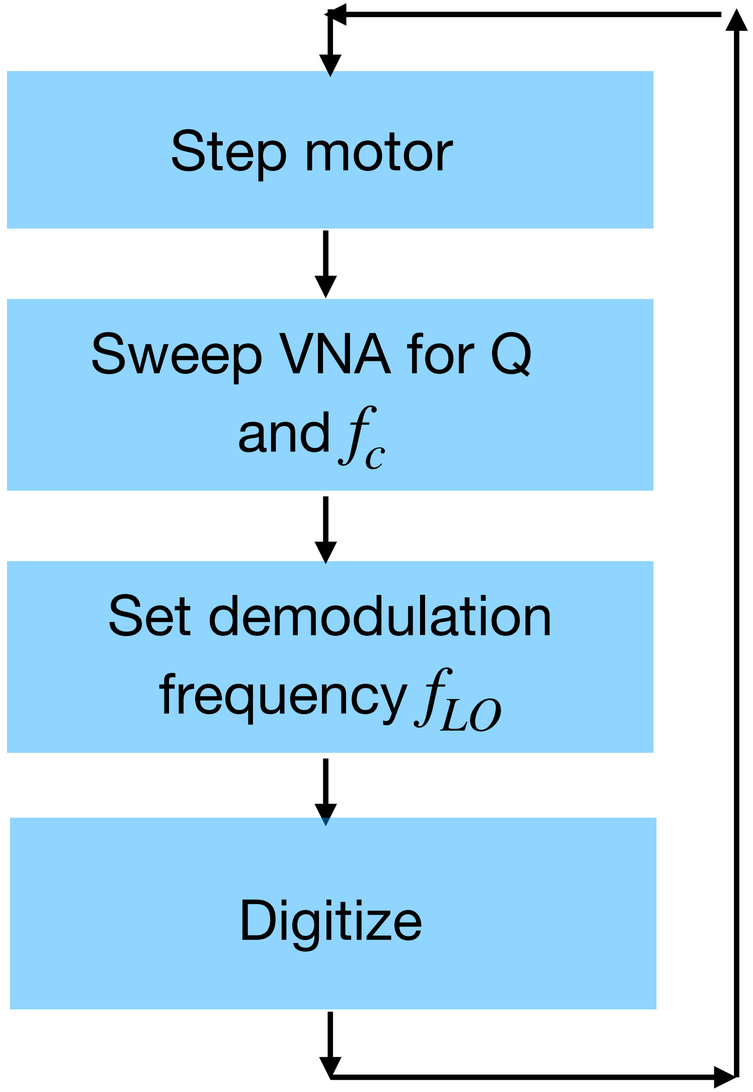


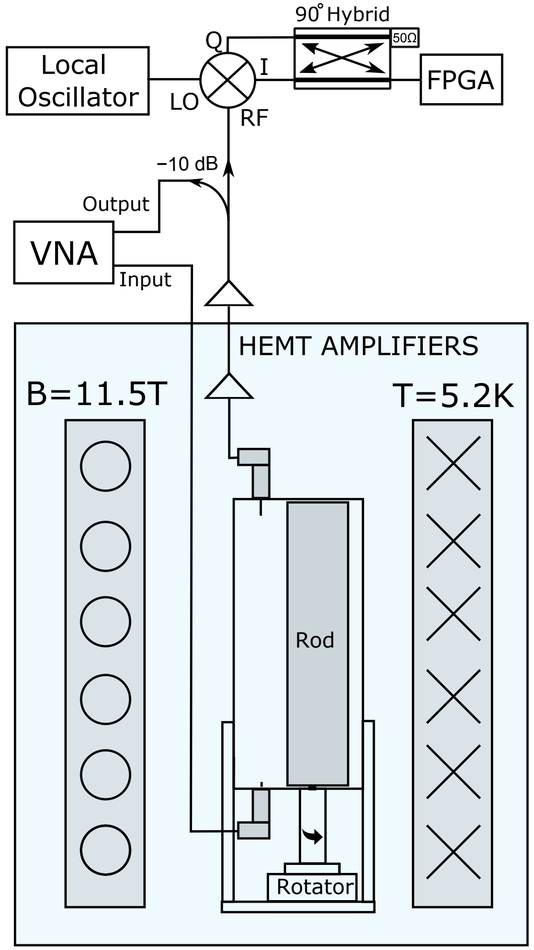


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a

- We scanned for ~ 3.5 weeks (~700MHz)
- ~ 600 cavity positions

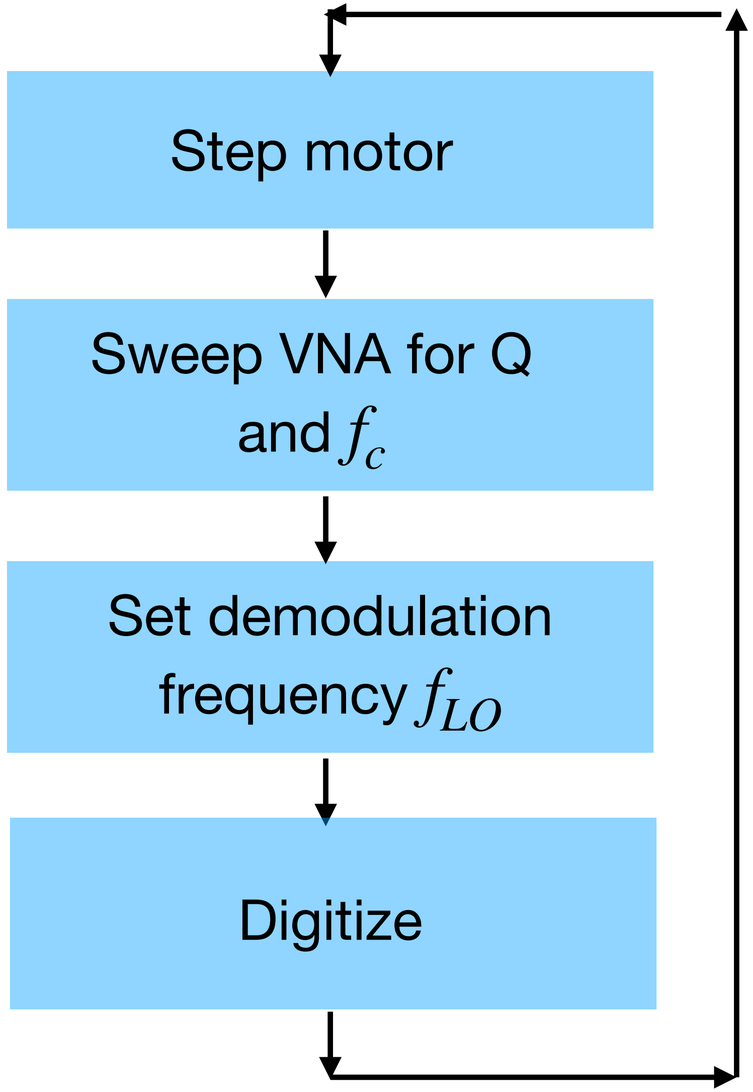


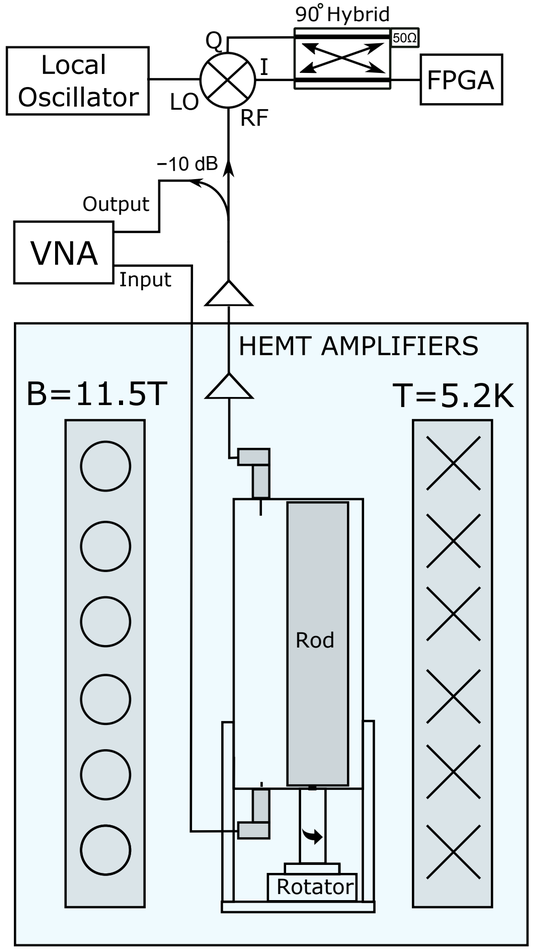


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a

- We scanned for ~ 3.5 weeks (~700MHz)
- ~ 600 cavity positions
- Typical values:

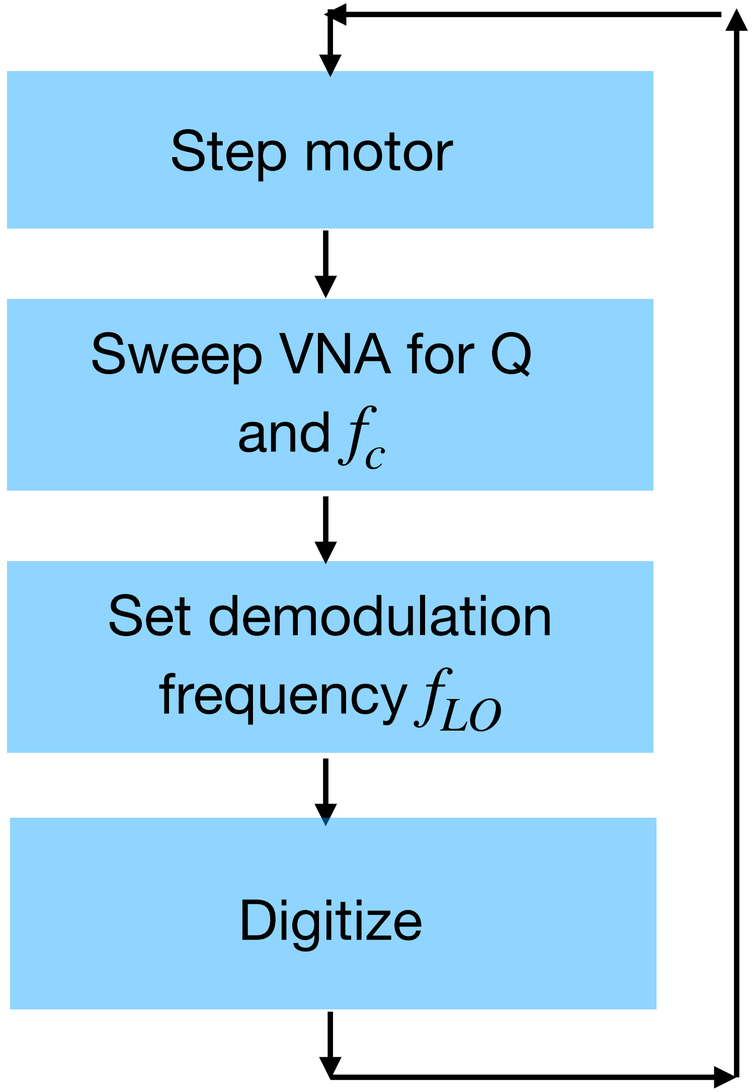


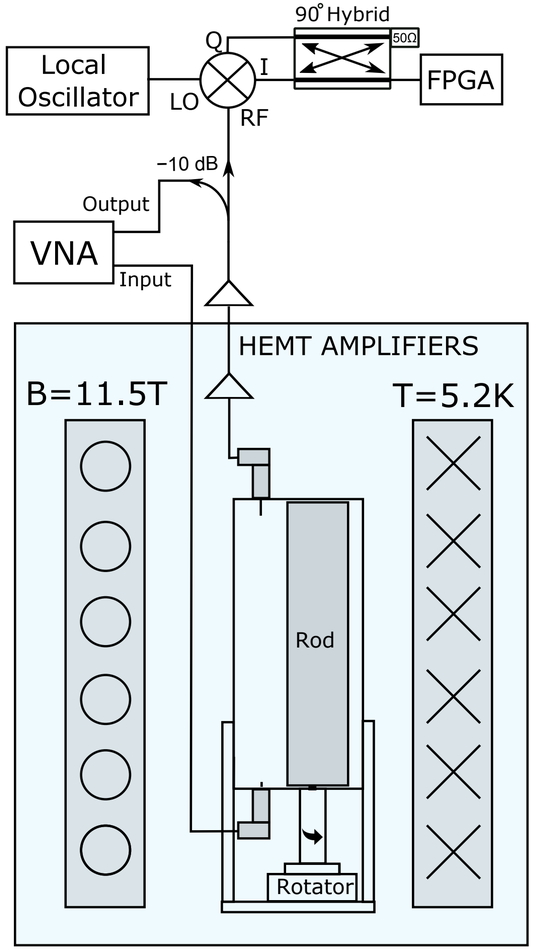


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a

- We scanned for ~ 3.5 weeks (~700MHz)
- ~ 600 cavity positions
- Typical values:
- $Q_L = 3500$

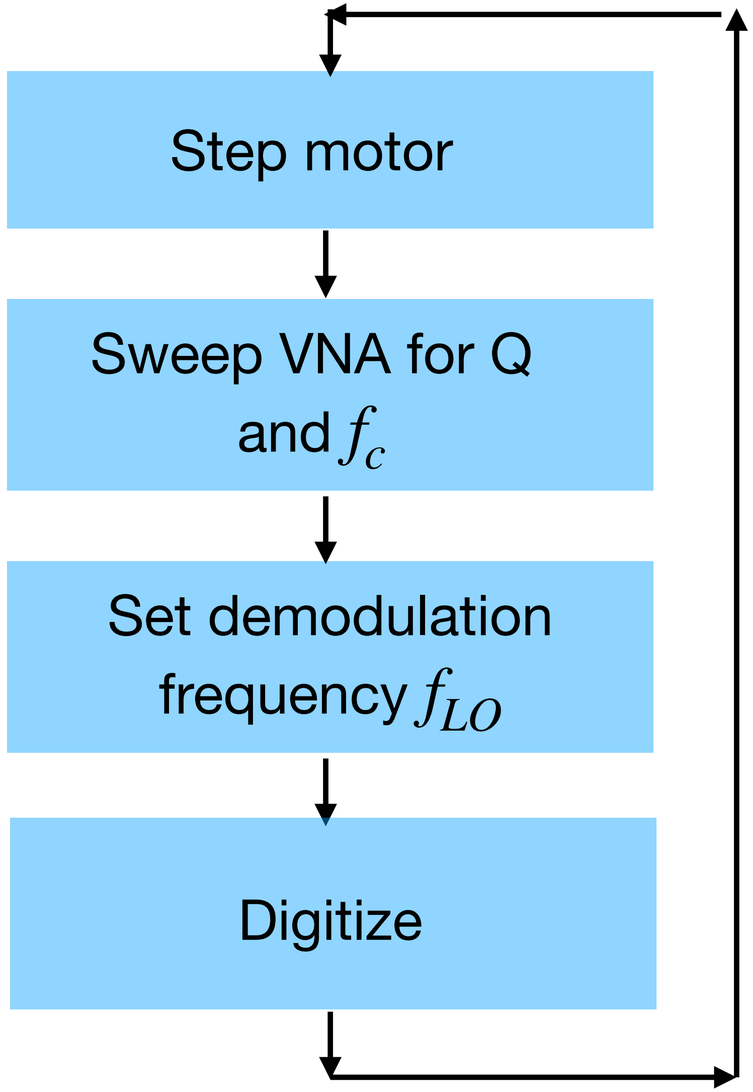


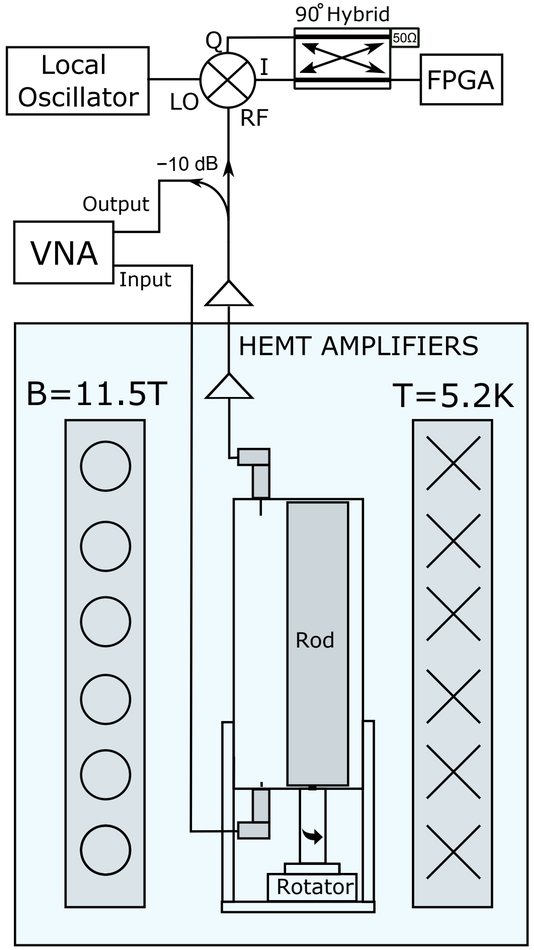


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a

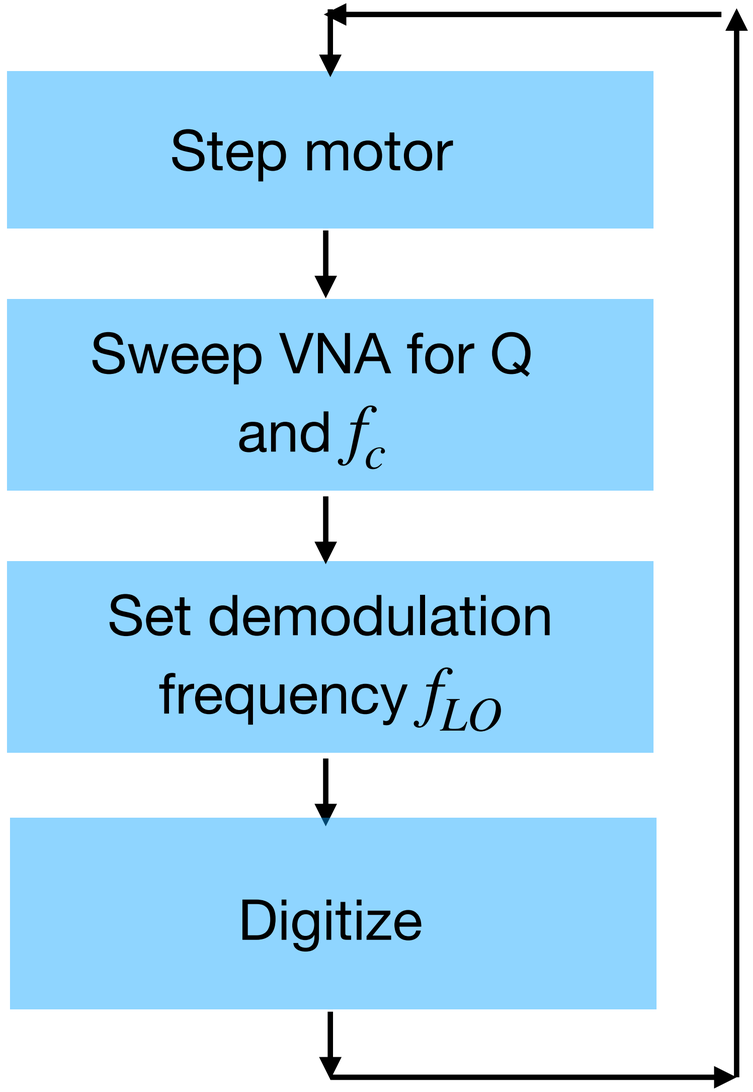
- We scanned for ~ 3.5 weeks (~700MHz)
- ~ 600 cavity positions
- Typical values:
- $Q_L = 3500$
- $T_{sys} = 6K$

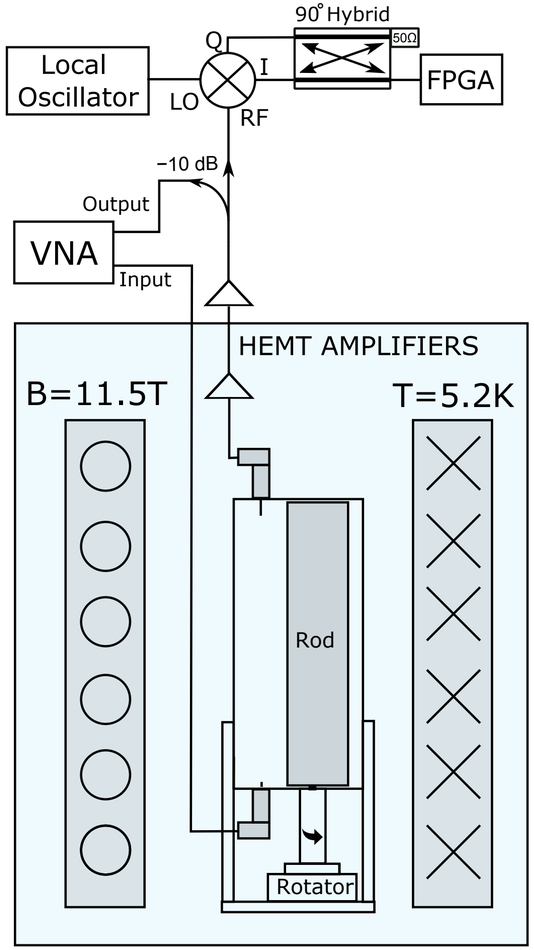




Phase 1a

- We scanned for ~ 3.5 weeks (~700MHz)
- ~ 600 cavity positions
- Typical values:
- $Q_L = 3500$
- $T_{sys} = 6K$
- $B_0 = 11.5T$

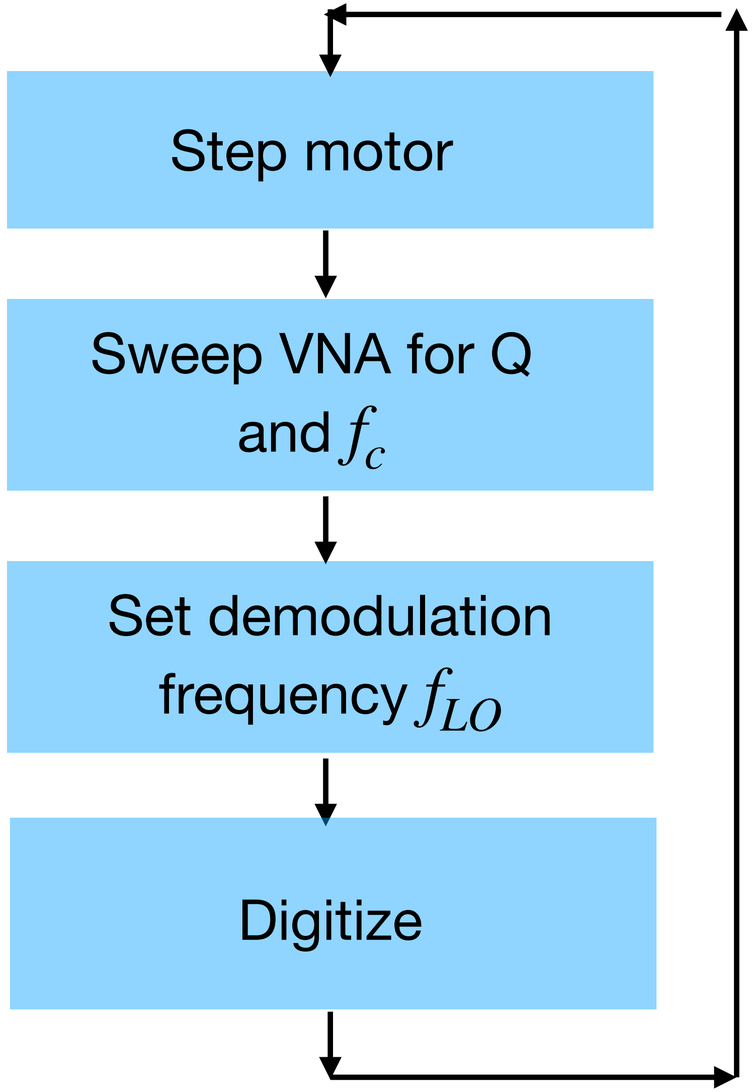


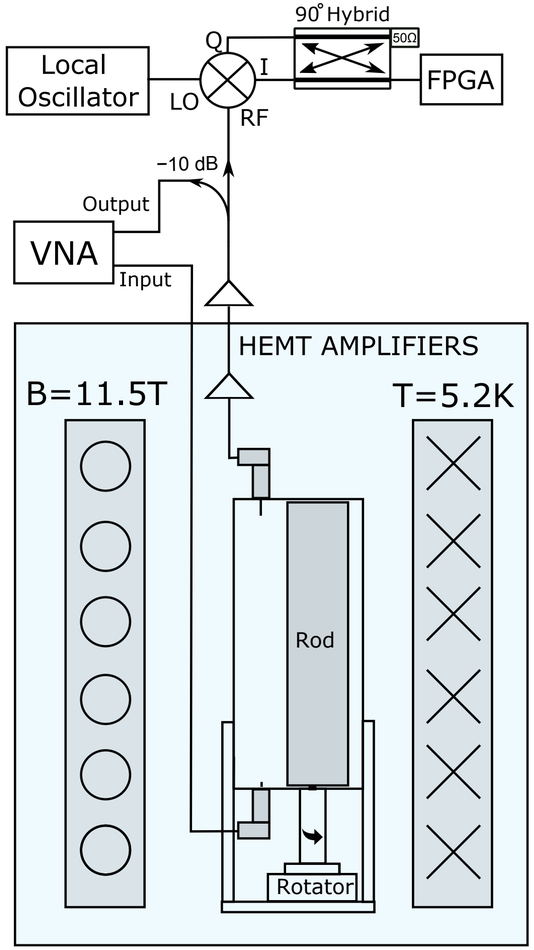


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a

- We scanned for ~ 3.5 weeks (~700MHz)
- ~ 600 cavity positions
- Typical values:
- $Q_L = 3500$
- $T_{sys} = 6K$
- $B_0 = 11.5T$
- IQ mixer and hybrid coupler for image rejection

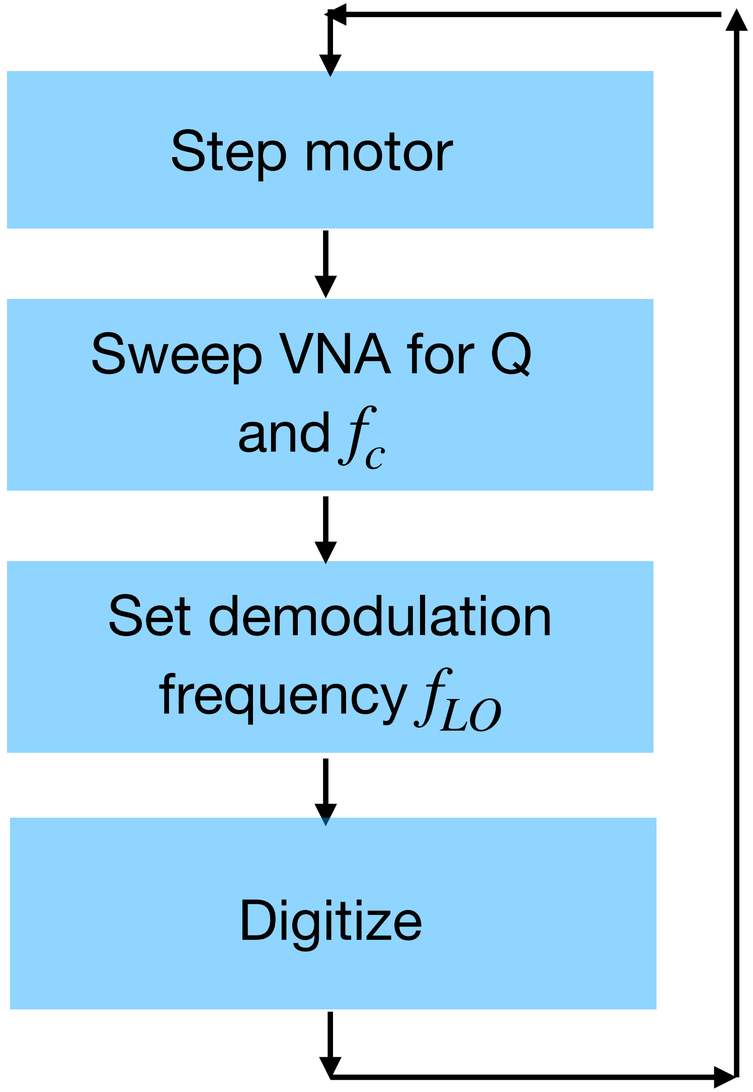


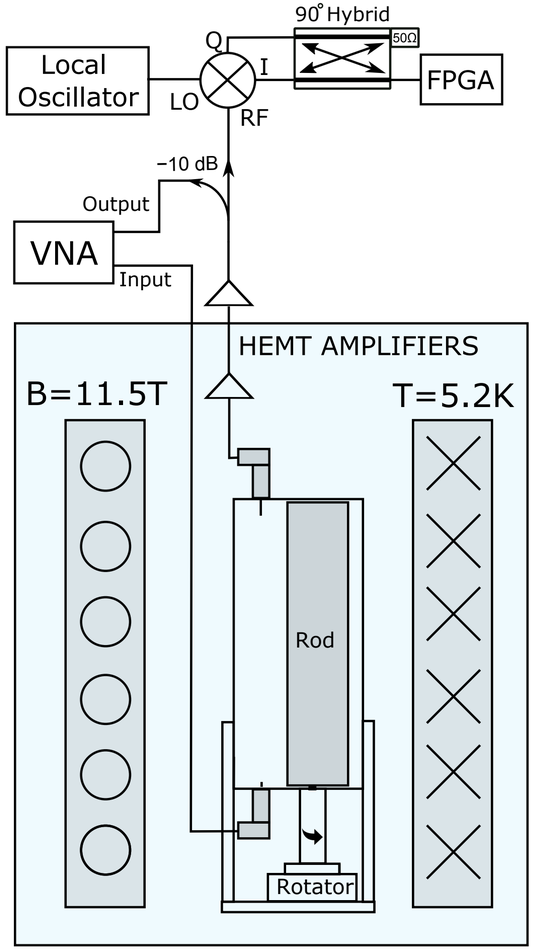


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a

- We scanned for ~ 3.5 weeks (~700MHz)
- ~ 600 cavity positions
- Typical values:
- $Q_L = 3500$
- $T_{sys} = 6K$
- $B_0 = 11.5T$
- IQ mixer and hybrid coupler for image rejection
- Zero dead time FFT on FPGA (from ANU)

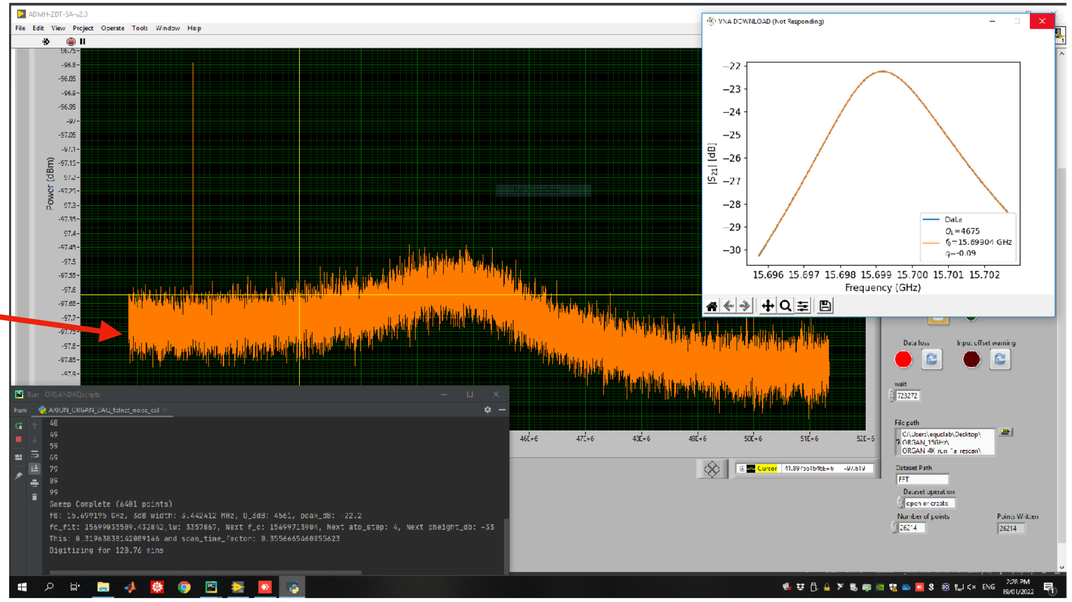




Data Taking

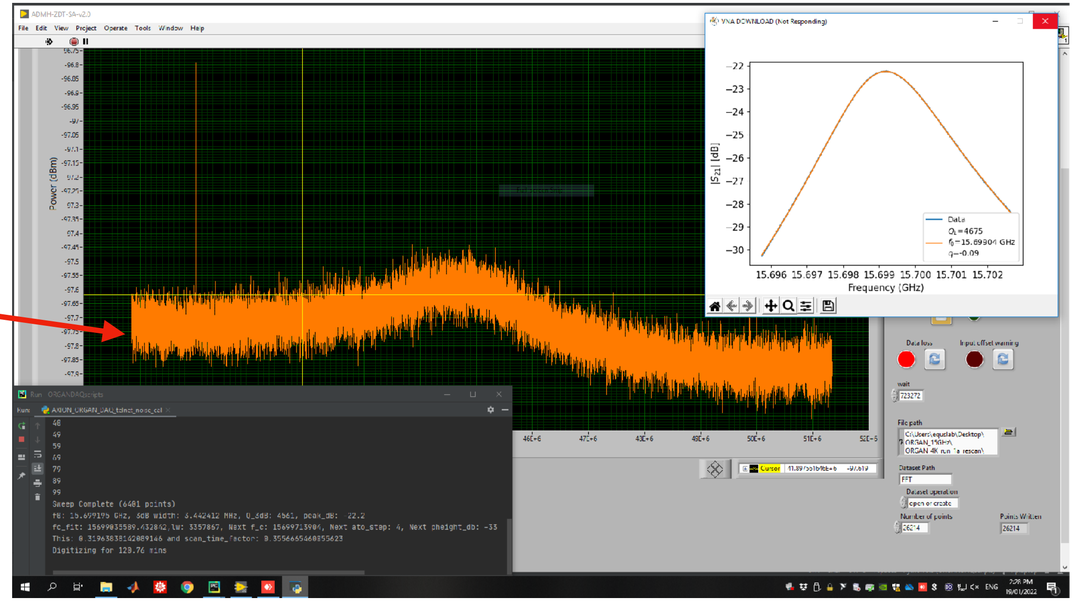
Data Taking

- ~12.5 MHz span FFT



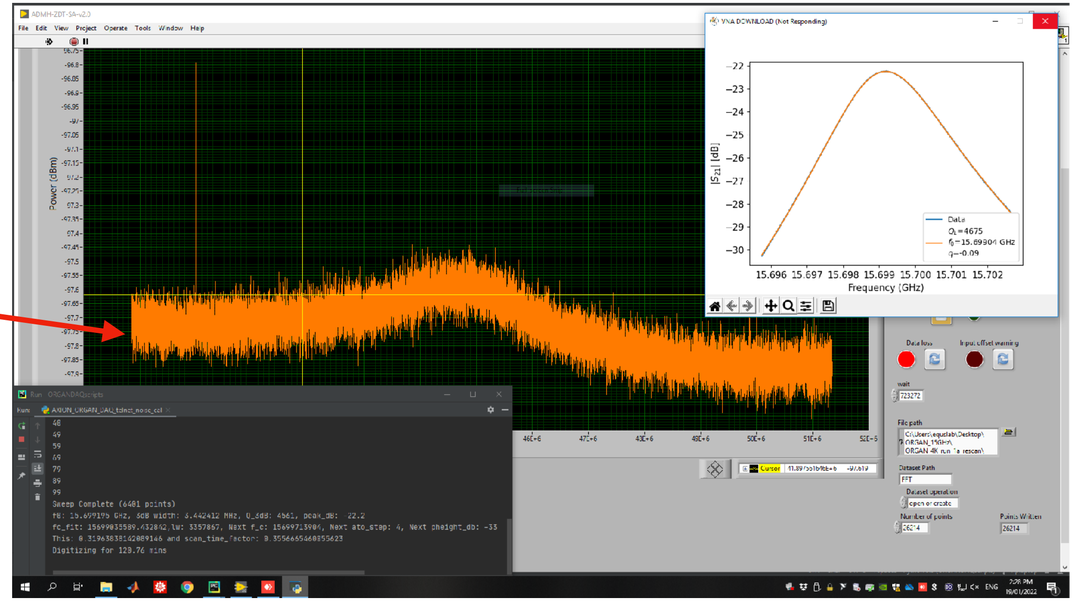
Data Taking

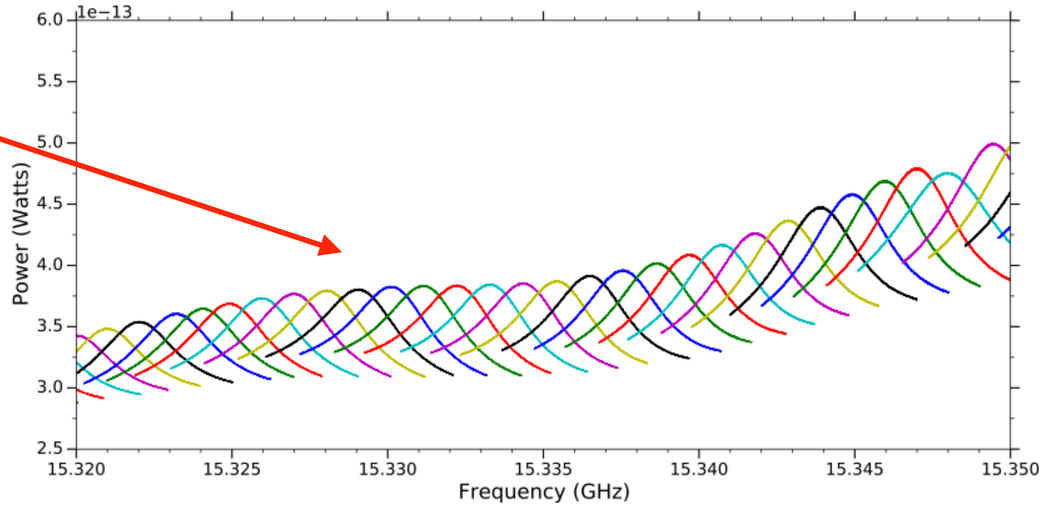
- ~12.5 MHz span FFT
- $\Delta\nu_{bin} \approx 477\,\text{Hz}$



Data Taking

- ~12.5 MHz span FFT
- $\Delta\nu_{bin} \approx 477\,\text{Hz}$
- Visible thermal profile of the cavity mode
- Thermal noise after many averages

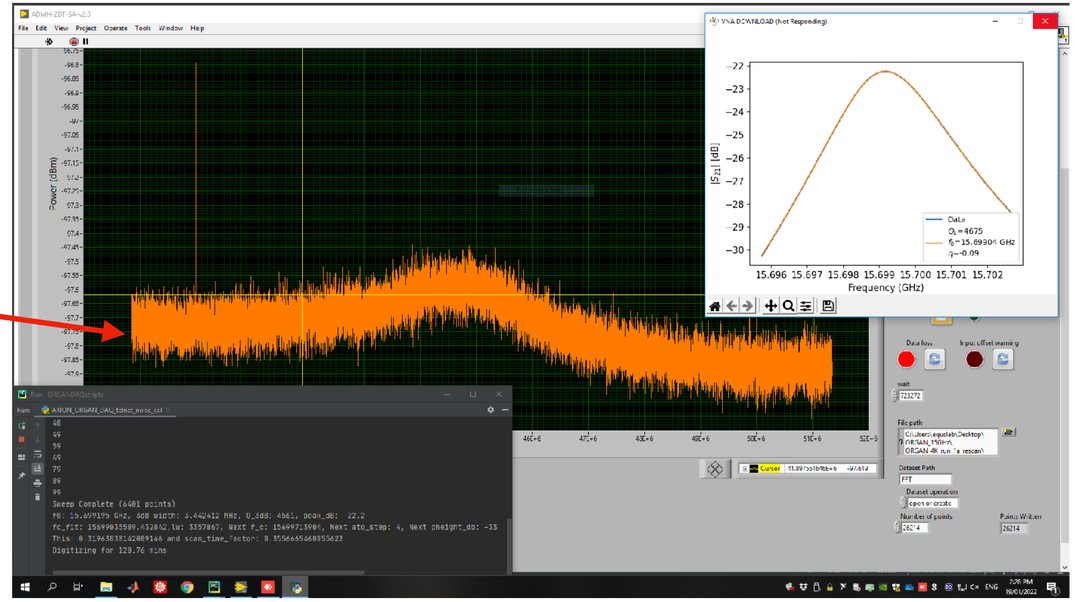


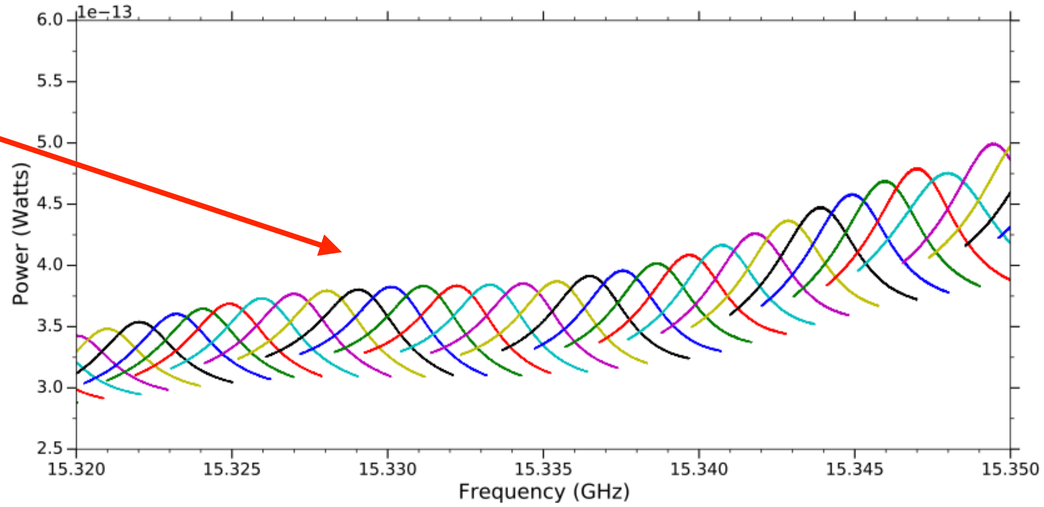


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Data Taking

- ~12.5 MHz span FFT
- $\Delta\nu_{bin} \approx 477$ Hz
- Visible thermal profile of the cavity mode
- Thermal noise after many averages
- Sum up all vertically overlapping RF bins





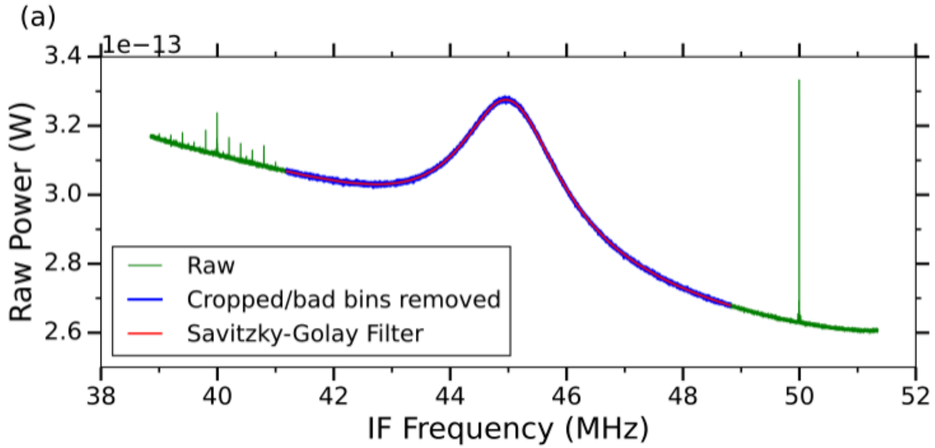
ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Data Analysis

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Data Analysis

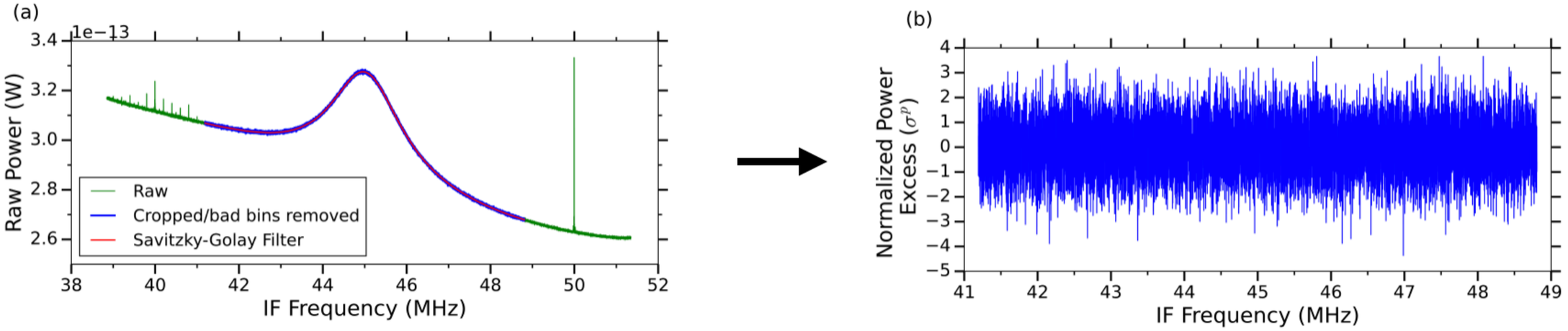
- Remove large scale baseline variations with Savitzky-Golay filter



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Data Analysis

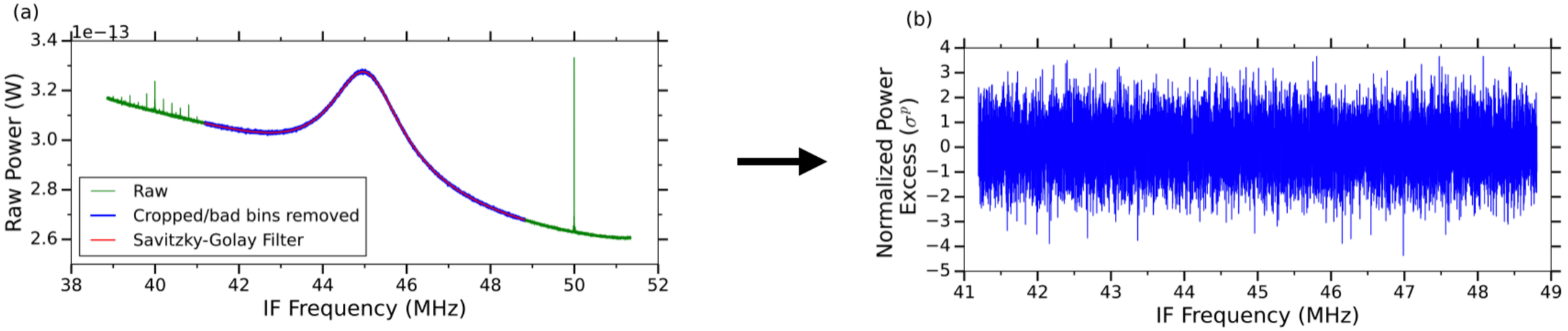
- Remove large scale baseline variations with Savitzky-Golay filter



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

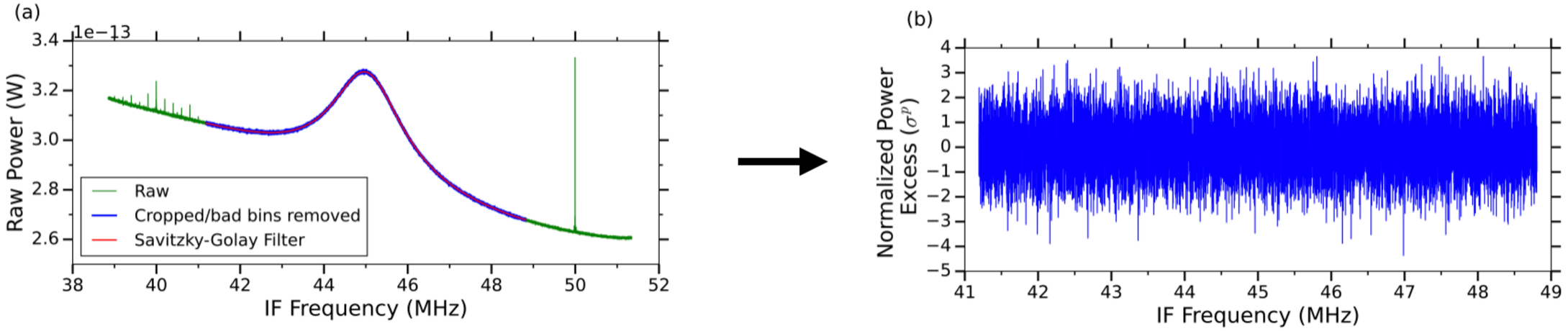
Data Analysis

- Remove large scale baseline variations with Savitzky-Golay filter
- Axions will appear as excess power above the mean thermal noise



Data Analysis

- Remove large scale baseline variations with Savitzky-Golay filter
- Axions will appear as excess power above the mean thermal noise
- $\Delta\nu_a \sim 32\Delta\nu_{bin}$ -> sum up adjacent bins due to axion lineshape

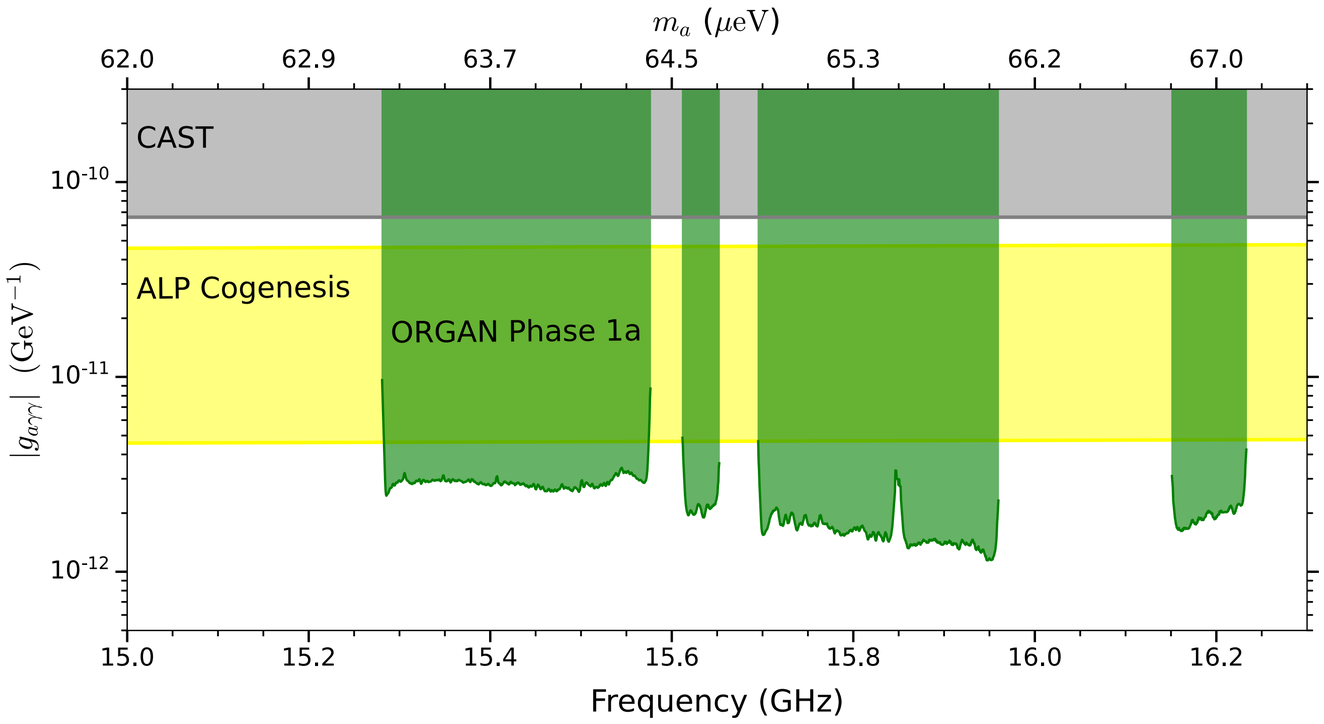


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a Limits

Phase 1a Limits

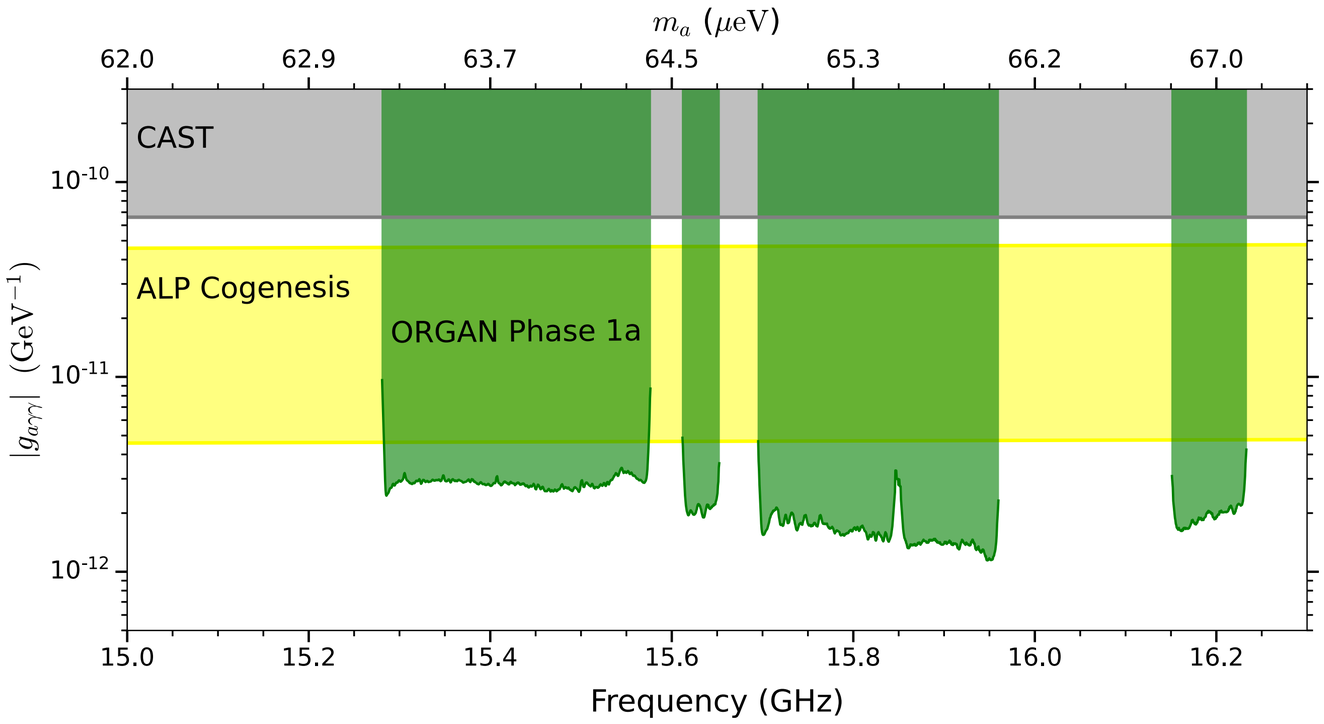
- Limits set between 15.28-16.23 GHz at $\sim 3 \times 10^{-12} g_{a\gamma\gamma}$ (ALP cogenesis)



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a Limits

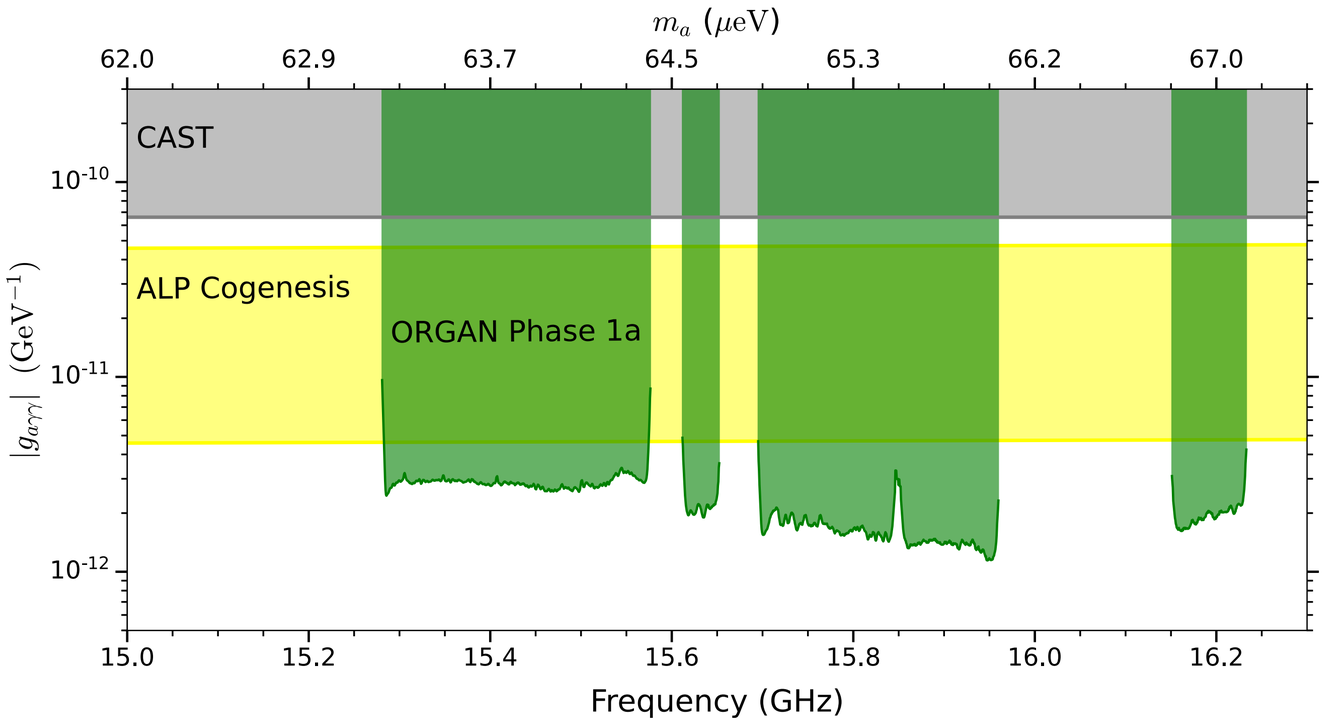
- Limits set between 15.28-16.23 GHz at $\sim 3 \times 10^{-12} g_{a\gamma\gamma}$ (ALP cogenesis)
- Most sensitive high frequency search yet



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a Limits

- Limits set between 15.28-16.23 GHz at $\sim 3 \times 10^{-12} g_{a\gamma\gamma}$ (ALP cogenesis)
- Most sensitive high frequency search yet
- Gaps to be filled in future phases



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Phase 1a Limits

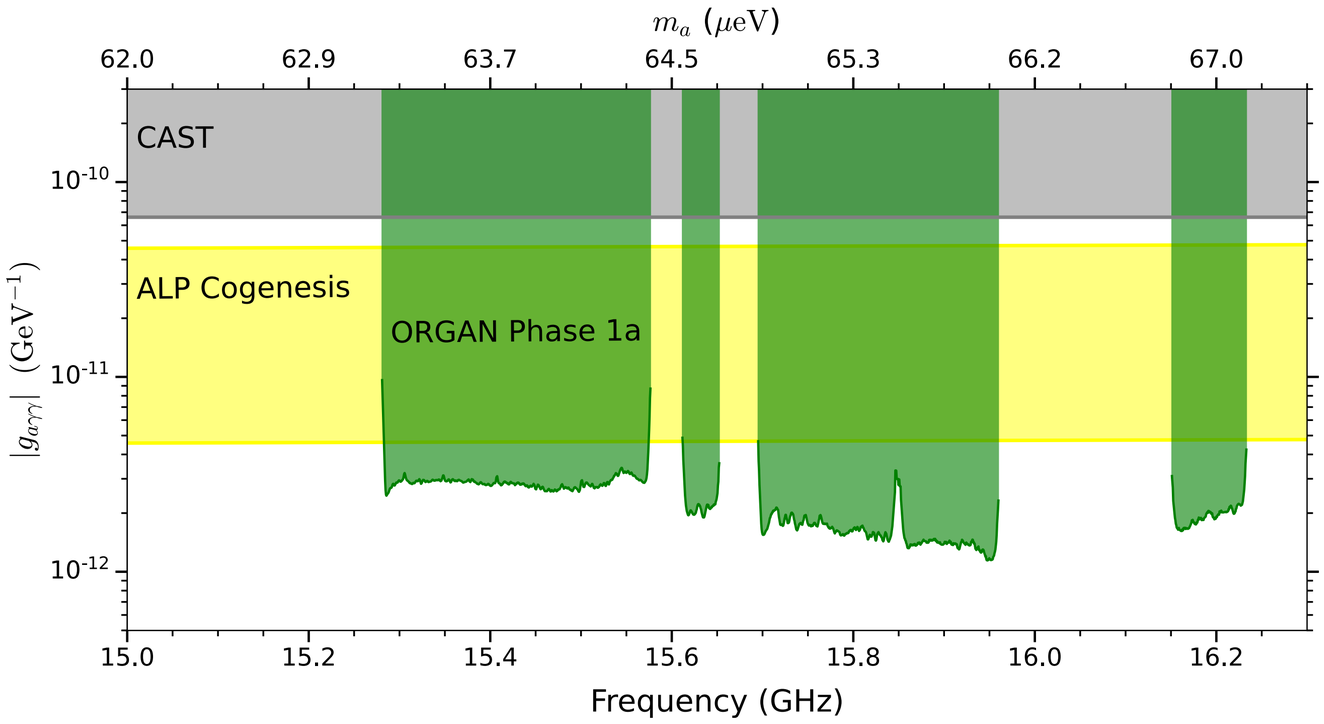
- Limits set between 15.28-16.23 GHz at $\sim 3 \times 10^{-12} g_{a\gamma\gamma}$ (ALP cogenesis)
- Most sensitive high frequency search yet
- Gaps to be filled in future phases
- Published now in Science Advances

SCIENCE ADVANCES | RESEARCH ARTICLE

PHYSICS

Direct search for dark matter axions excluding ALP cogenesis in the 63- to 67-μeV range with the ORGAN experiment

Aaron Quiskamp[1]*, Ben T. McAllister[1,2]*, Paul Altin[3], Eugene N. Ivanov[1], Maxim Goryachev[1], Michael E. Tobar[1]*



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Improving Sensitivity

Improving Sensitivity

- Decrease T_{sys}: Run at mK temperatures and use quantum limited amps

Improving Sensitivity

- Decrease T_{sys}: Run at mK temperatures and use quantum limited amps
- Increase V: Multiple cavities

Improving Sensitivity

- Decrease T_{sys}: Run at mK temperatures and use quantum limited amps
- Increase V: Multiple cavities
- Increase Q_{cav}: Superconducting cavities with $Q \sim 10^5 - 10^6$

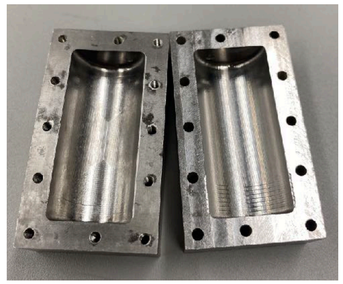
Sputtered Nb_3Sn

Bulk NbTi

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Improving Sensitivity

- Decrease T_{sys}: Run at mK temperatures and use quantum limited amps
- Increase V: Multiple cavities
- Increase Q_{cav}: Superconducting cavities with $Q \sim 10^5 - 10^6$



Sputtered Nb_3Sn

Bulk NbTi

ORGAN Q

- 6-7 GHz clamshell cavity
- Using a JPA at mK
- Plan 5-10 x KSVZ sensitivity
- Commence in 2023 in 7 T Magnet

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ADMX Collaboration

The ADMX Collaboration

ADMX is an international collaboration composed of researchers from University of Washington, University of Florida, Lawrence Livermore National Laboratory, Fermi National Laboratory, Pacific Northwest National Laboratory, UC Berkeley, Washington University in St. Louis, Sheffield University, and the National Radio Astronomy Observatory.

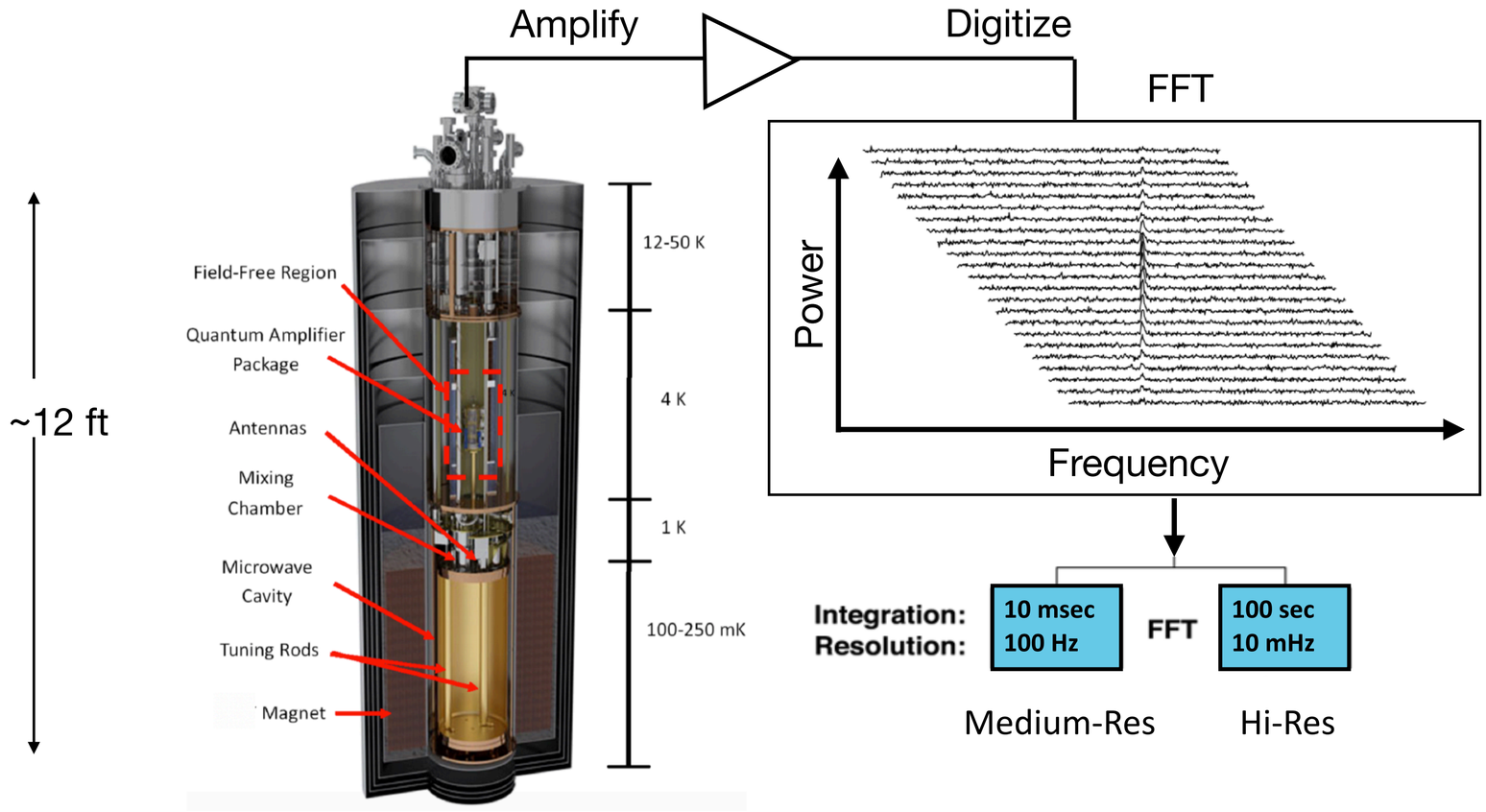
ADMX Collaboration Meeting Summer 2017

- Axion Dark Matter eXperiment (ADMX)
- UWA is one of the nodes of ADMX

ADMX
AXION DARK MATTER EXPERIMENT

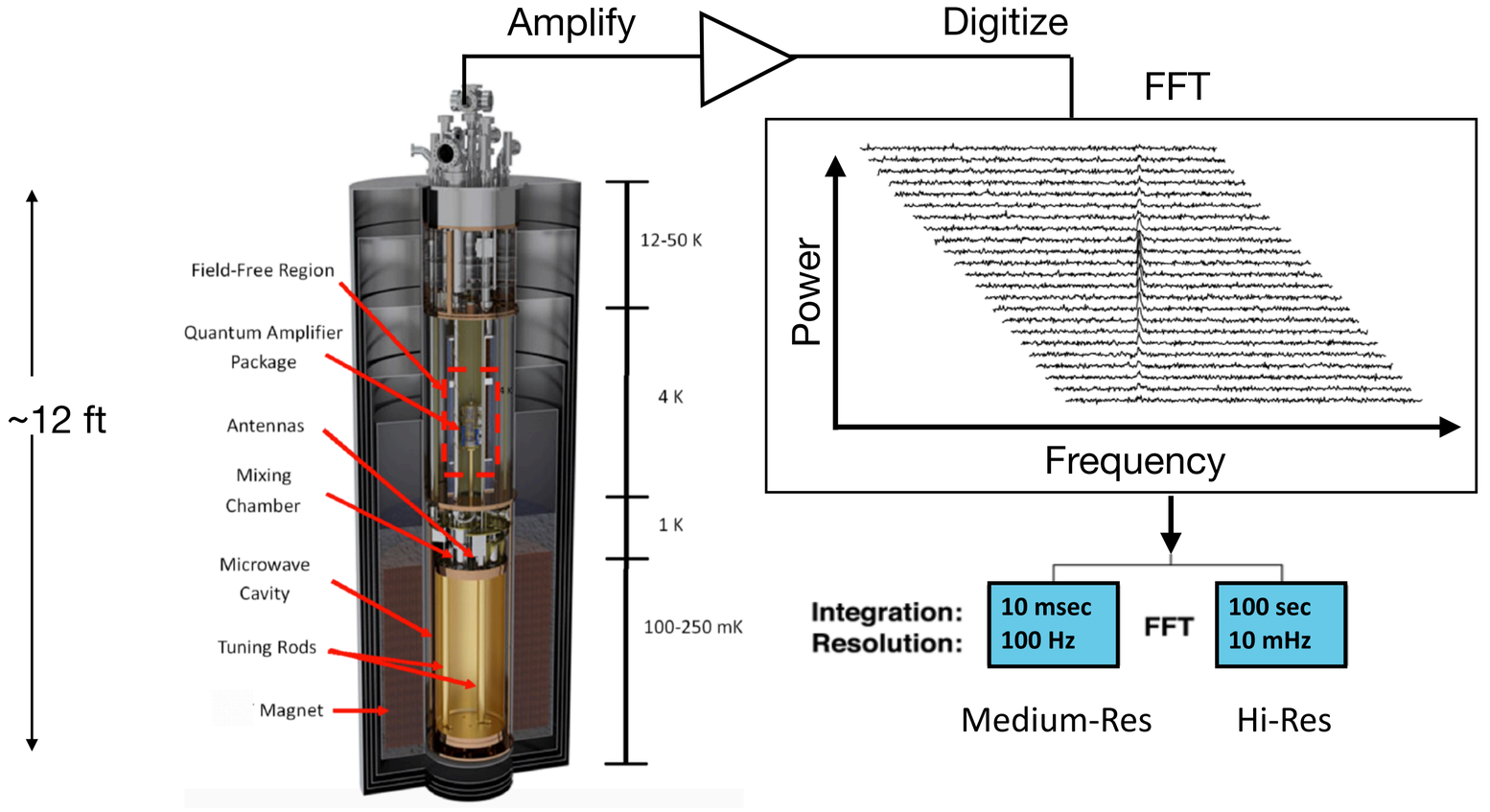
ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ADMX so far



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ADMX so far



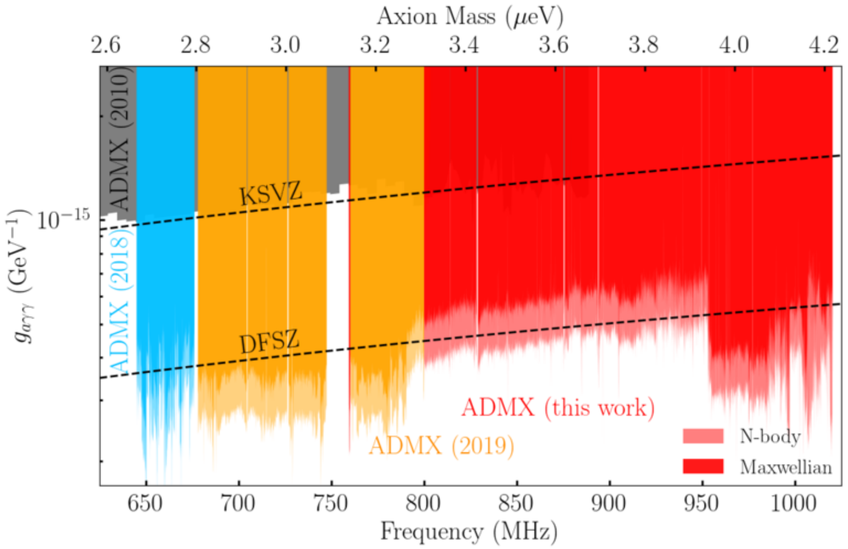
PHYSICAL REVIEW LETTERS 127, 261803 (2021)

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]

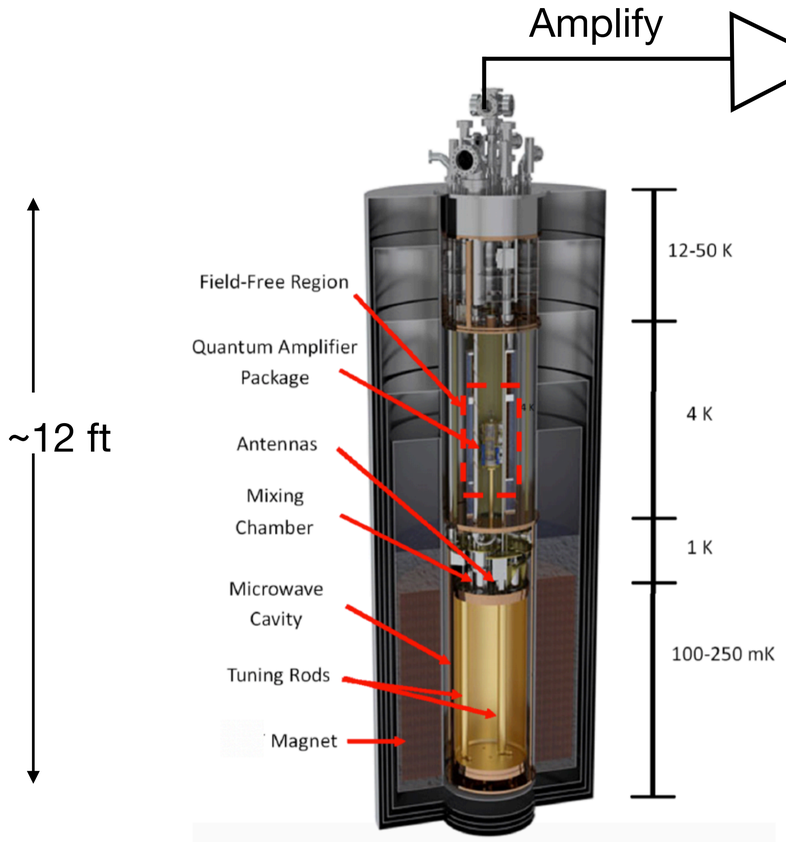
(ADMX Collaboration)

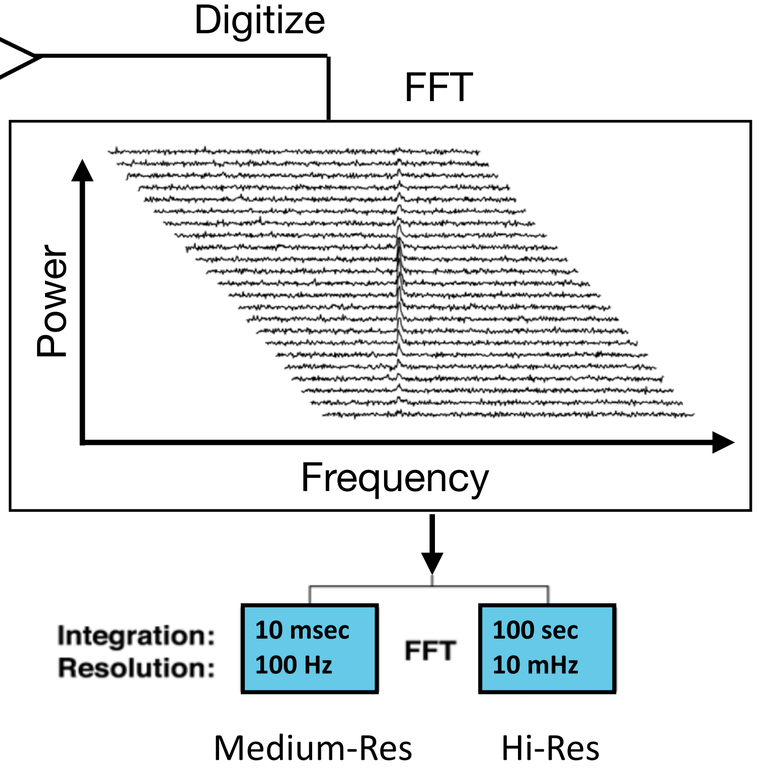


Reached DFSZ sensitivity!

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ADMX so far





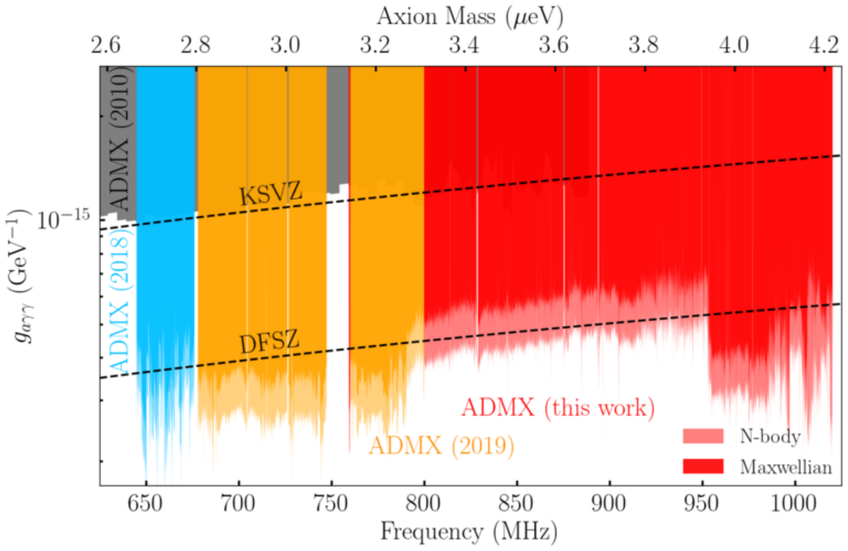
PHYSICAL REVIEW LETTERS 127, 261803 (2021)

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]

(ADMX Collaboration)

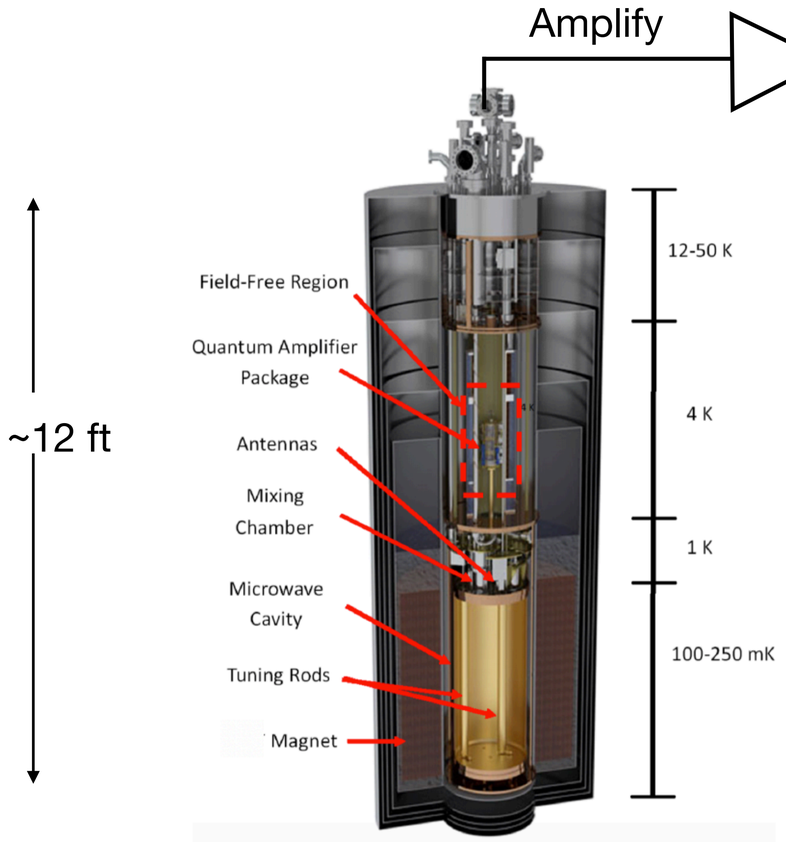


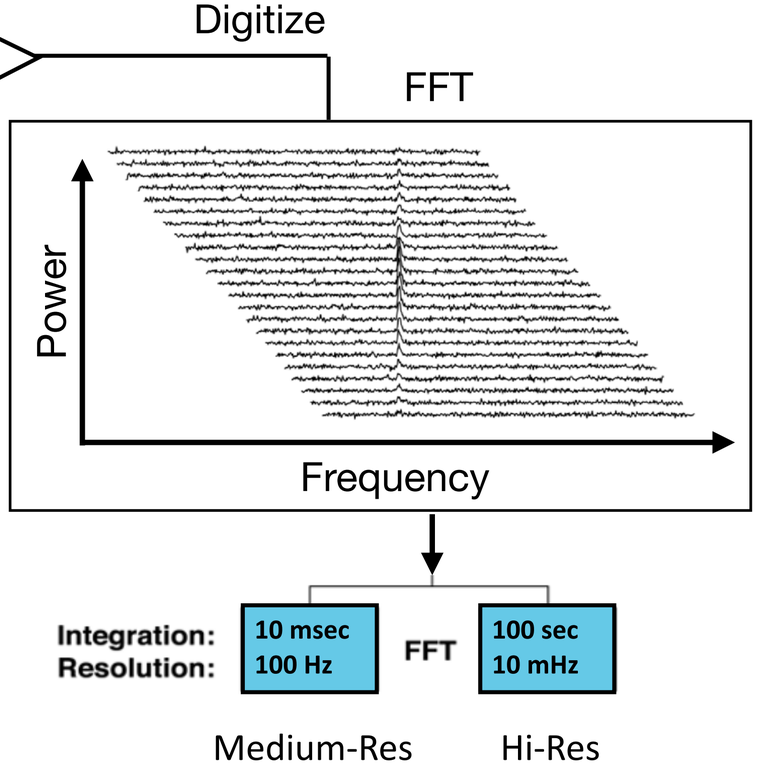
Reached DFSZ sensitivity!

- "Medium Resolution" channel searches for **virialized** axions

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

ADMX so far





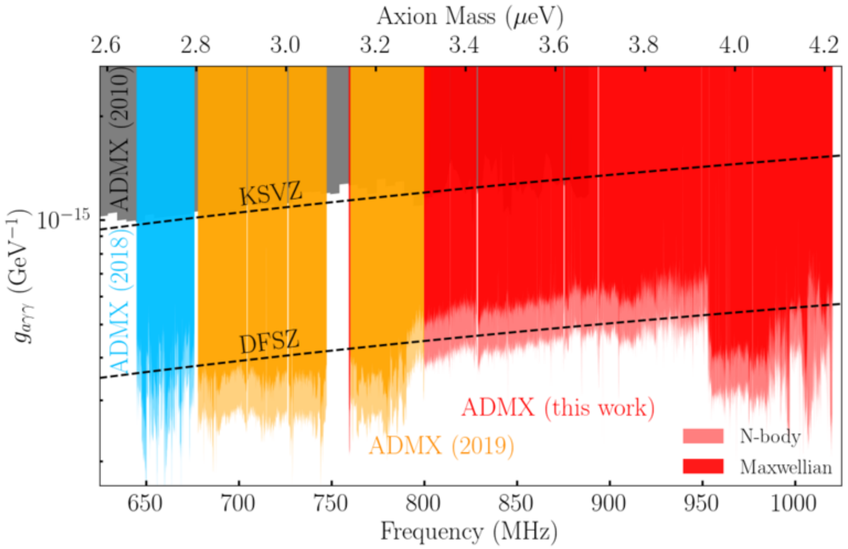
PHYSICAL REVIEW LETTERS 127, 261803 (2021)

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]

(ADMX Collaboration)



Reached DFSZ sensitivity!

- "Medium Resolution" channel searches for **virialized** axions
- There is also a "High Resolution" channel searching for **non-virialized** axions

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Non-Virialized Axions

Non-Virialized Axions

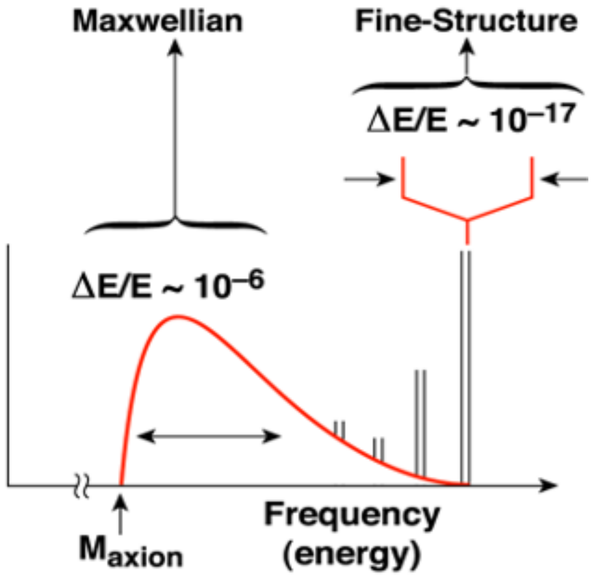
- Late infall axions have not yet thermalized with the rest of the galactic halo

Non-Virialized Axions

- Late infall axions have not yet thermalized with the rest of the galactic halo
- $$\frac{\delta f}{f} = \frac{\delta E}{E} \approx \frac{v \delta v}{c^2}$$

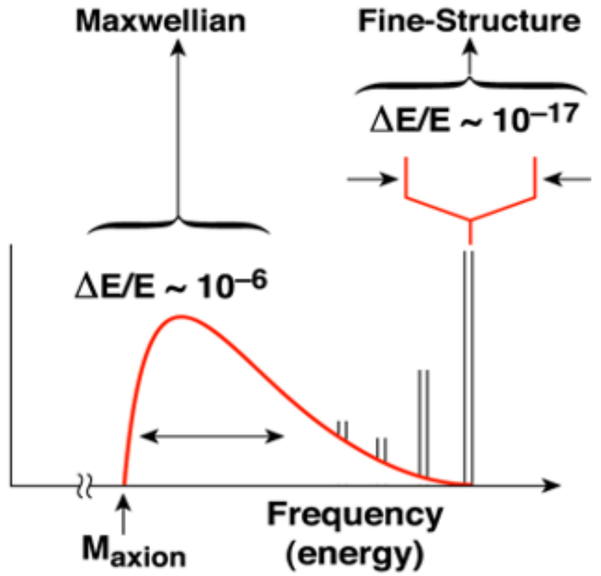
Non-Virialized Axions

- Late infall axions have not yet thermalized with the rest of the galactic halo
- $$\frac{\delta f}{f} = \frac{\delta E}{E} \approx \frac{v \delta v}{c^2}$$
- Cold axion flows have very narrow velocity dispersions



Non-Virialized Axions

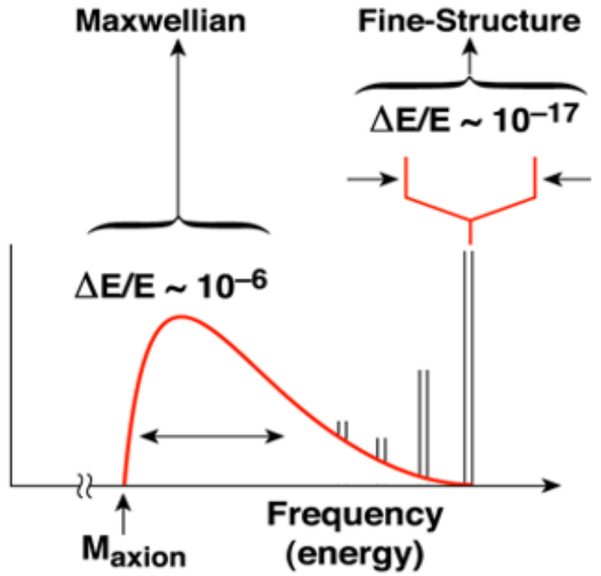
- Late infall axions have not yet thermalized with the rest of the galactic halo
- $$\frac{\delta f}{f} = \frac{\delta E}{E} \approx \frac{v \delta v}{c^2}$$
- Cold axion flows have very narrow velocity dispersions
- $Q_a \sim 10^9$ (higher/lower depending on the flow)



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

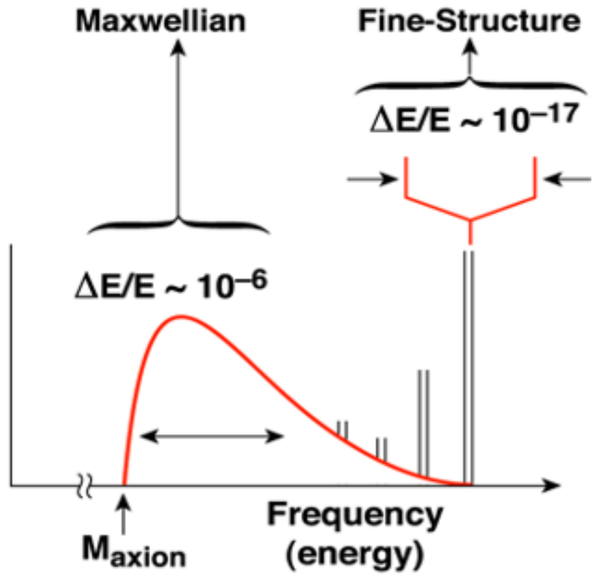
Non-Virialized Axions

- Late infall axions have not yet thermalized with the rest of the galactic halo
- $$\frac{\delta f}{f} = \frac{\delta E}{E} \approx \frac{v \delta v}{c^2}$$
- Cold axion flows have very narrow velocity dispersions
- $Q_a \sim 10^9$ (higher/lower depending on the flow)
- For ADMX @ 850MHz & the “Big Flow”, $\Delta f \lesssim$ 480 mHz



Non-Virialized Axions

- Late infall axions have not yet thermalized with the rest of the galactic halo
- $\frac{\delta f}{f} = \frac{\delta E}{E} \approx \frac{v \delta v}{c^2}$
- Cold axion flows have very narrow velocity dispersions
- $Q_a \sim 10^9$ (higher/lower depending on the flow)
- For ADMX @ 850MHz & the “Big Flow”, $\Delta f \lesssim$ 480 mHz
- Cold flows **could** have axion density greater $\rho_a \rightarrow$ **Improved discovery potential**



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

HiRes Search

HiRes Search

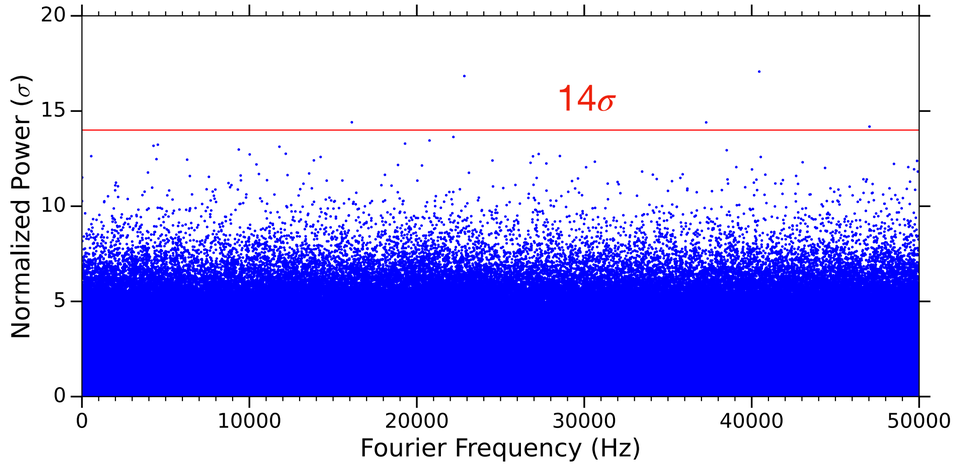
- Exponential distribution

HiRes Search

- Exponential distribution
- Choose some threshold cut $\rightarrow 14\sigma$

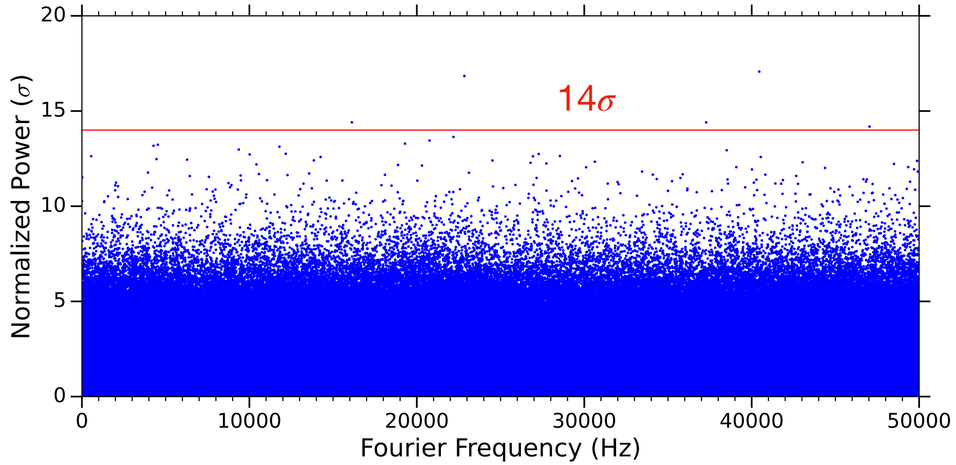
HiRes Search

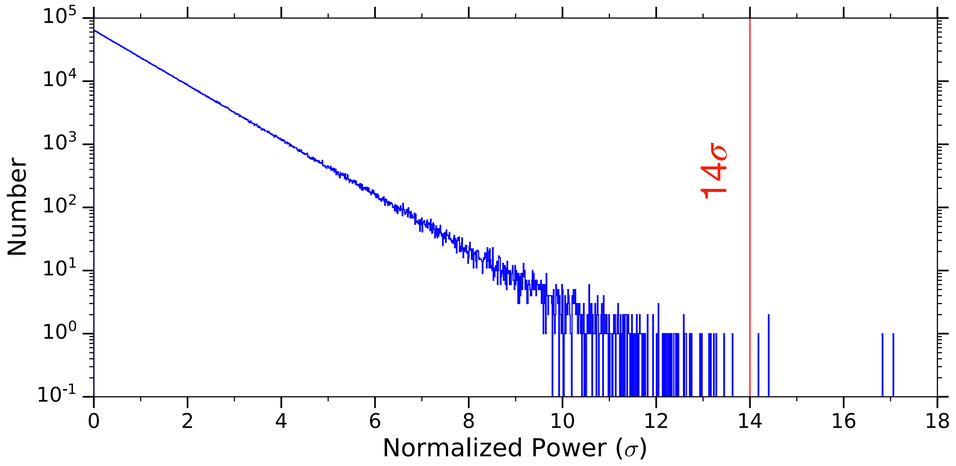
- Exponential distribution
- Choose some threshold cut $\rightarrow 14\sigma$



HiRes Search

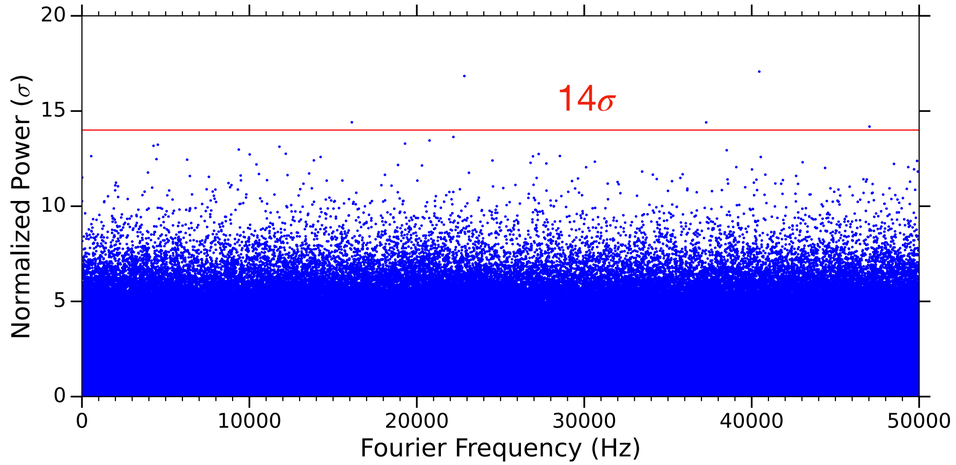
- Exponential distribution
- Choose some threshold cut $\rightarrow 14\sigma$

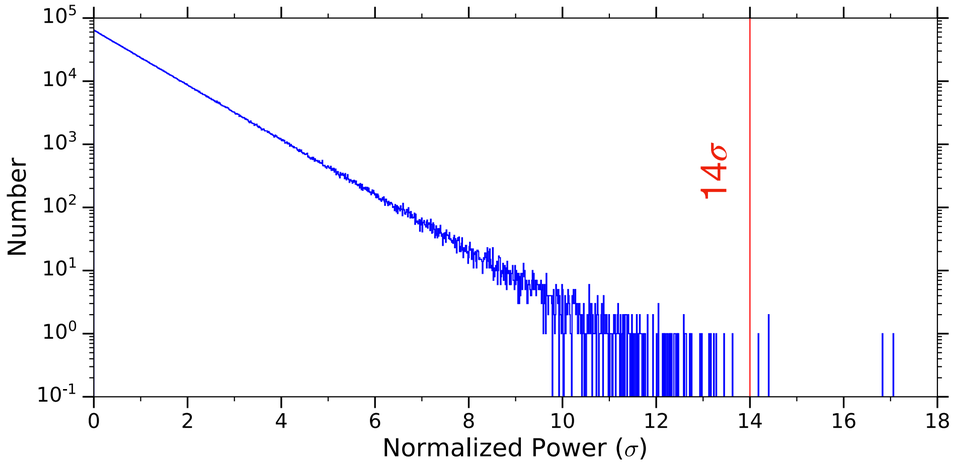




HiRes Search

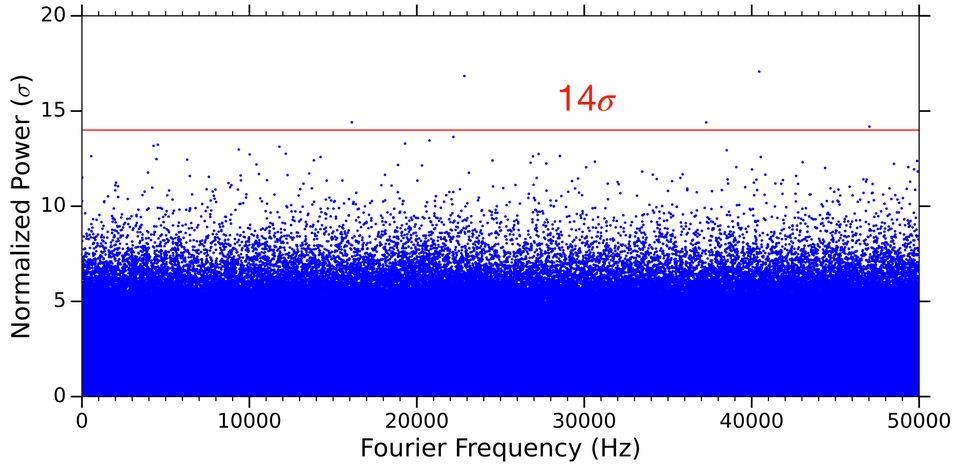
- Exponential distribution
- Choose some threshold cut $\rightarrow 14\sigma$
- Anything above 14σ is a “trigger”

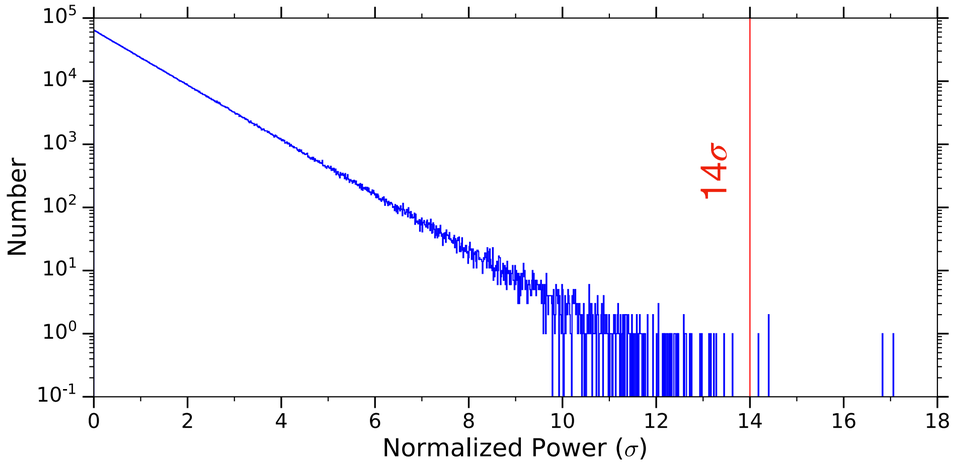




HiRes Search

- Exponential distribution
- Choose some threshold cut $\rightarrow 14\sigma$
- Anything above 14σ is a “trigger”
- If this trigger is an **axion** it should be **persistent** across scans

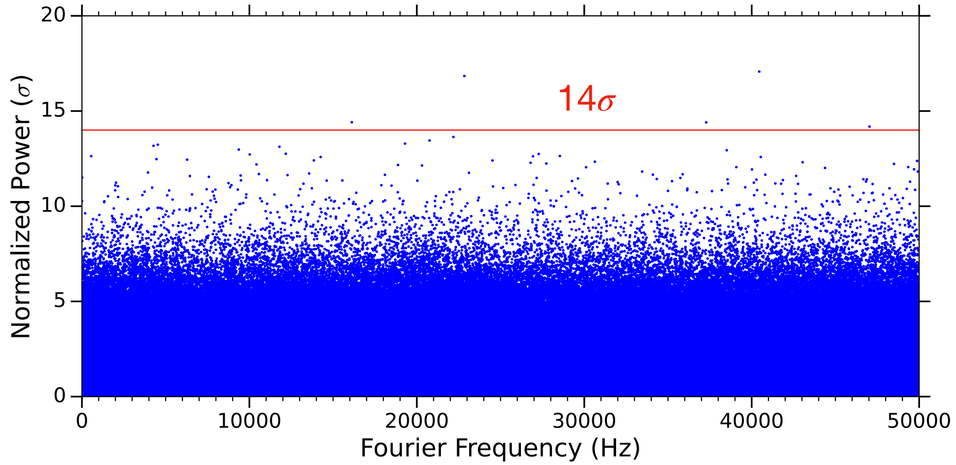


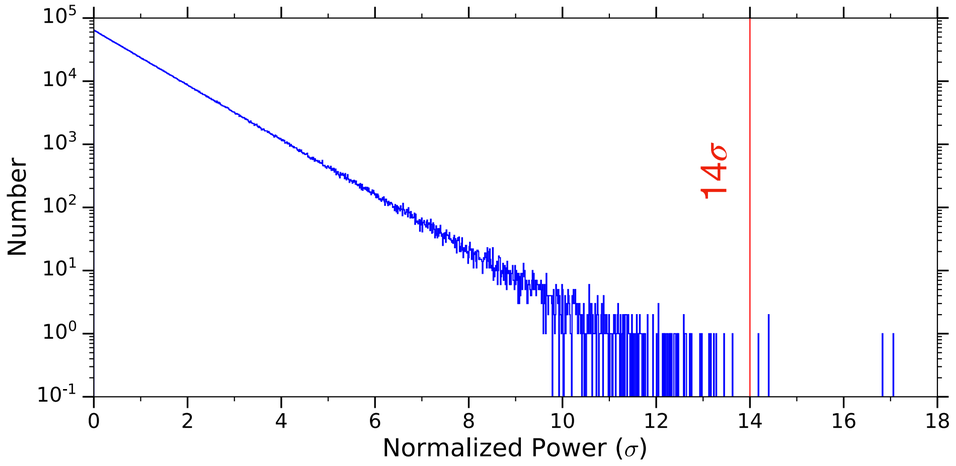


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

HiRes Search

- Exponential distribution
- Choose some threshold cut $\rightarrow 14\sigma$
- Anything above 14σ is a “trigger”
- If this trigger is an **axion** it should be **persistent** across scans
- An axion should also **enhance** with the cavity Lorentzian line shape

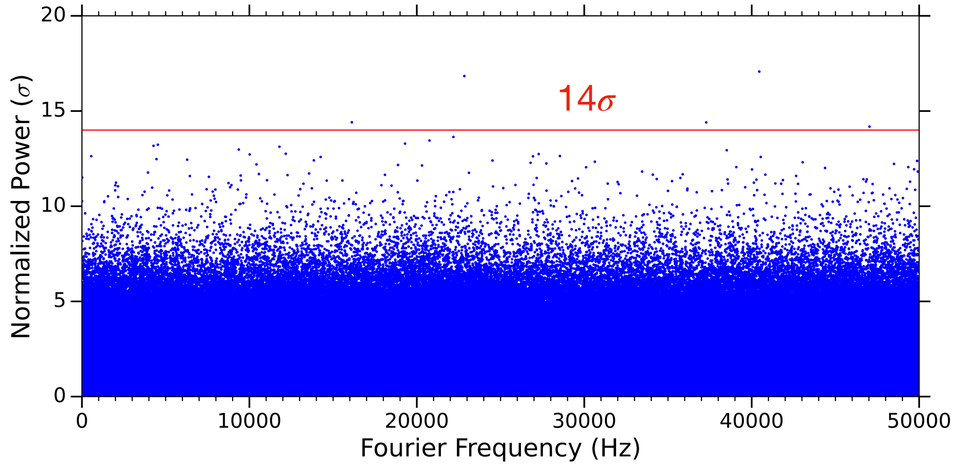


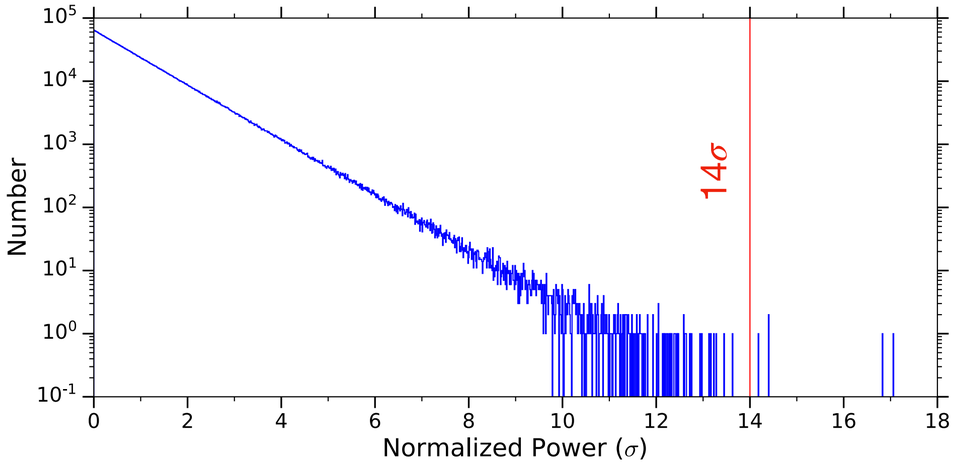


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

HiRes Search

- Exponential distribution
- Choose some threshold cut $\rightarrow 14\sigma$
- Anything above 14σ is a “trigger”
- If this trigger is an **axion** it should be **persistent** across scans
- An axion should also **enhance** with the cavity Lorentzian line shape
- Diurnal and sidereal modulation





Low Frequency ADMX & ORGAN

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Low Frequency ADMX & ORGAN

- ADMX future searches will take place inside large MRI magnet to be housed at Fermilab

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Low Frequency ADMX & ORGAN

- ADMX future searches will take place inside large MRI magnet to be housed at Fermilab
- Low frequency working group led by Ben McAllister

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Low Frequency ADMX & ORGAN

- ADMX future searches will take place inside large MRI magnet to be housed at Fermilab
- Low frequency working group led by Ben McAllister
- One area of interest is low mass range (100-500 MHz)

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Low Frequency ADMX & ORGAN

- ADMX future searches will take place inside large MRI magnet to be housed at Fermilab
- Low frequency working group led by Ben McAllister
- One area of interest is low mass range (100-500 MHz)
- Cavities are just too big to reach ~100 MHz

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

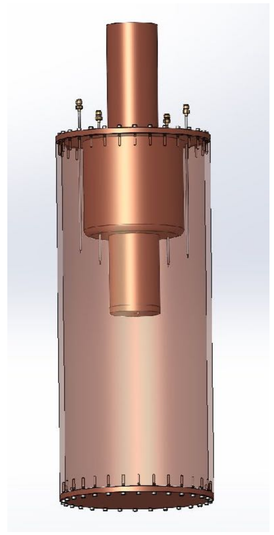
Low Frequency ADMX & ORGAN

- ADMX future searches will take place inside large MRI magnet to be housed at Fermilab
- Low frequency working group led by Ben McAllister
- One area of interest is low mass range (100-500 MHz)
- Cavities are just too big to reach ~100 MHz
- Re-entrant cavity or novel design needed

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Low Frequency ADMX & ORGAN

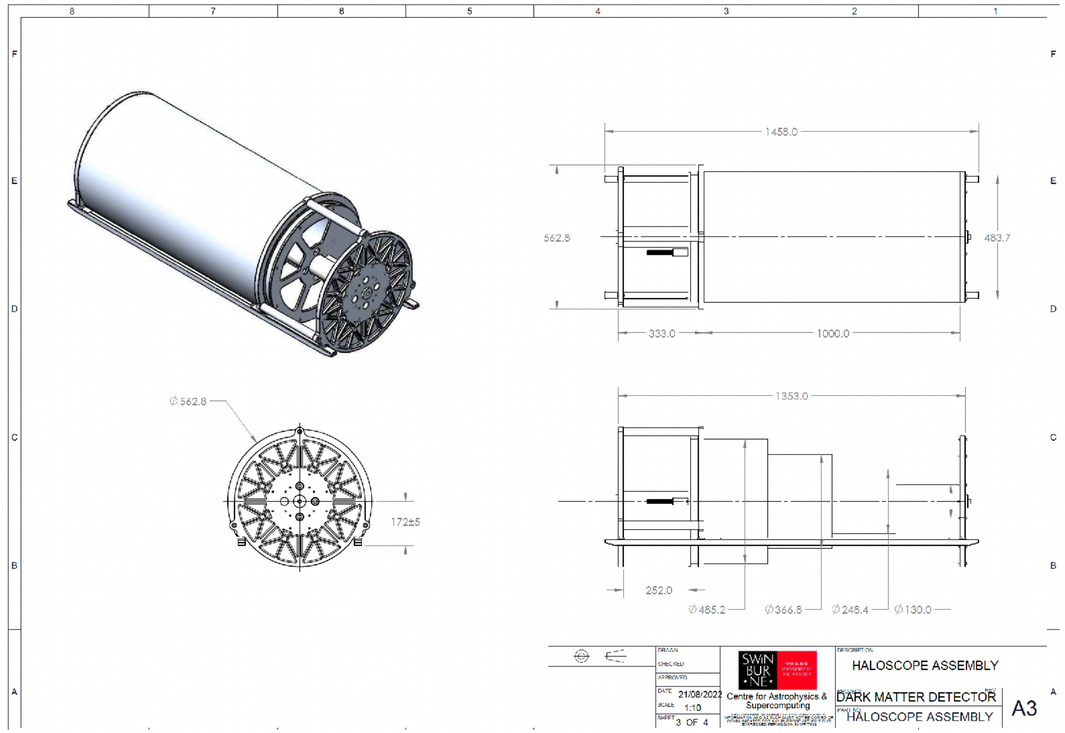
- ADMX future searches will take place inside large MRI magnet to be housed at Fermilab
- Low frequency working group led by Ben McAllister
- One area of interest is low mass range (100-500 MHz)
- Cavities are just too big to reach ~100 MHz
- Re-entrant cavity or novel design needed



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Low Frequency ADMX & ORGAN

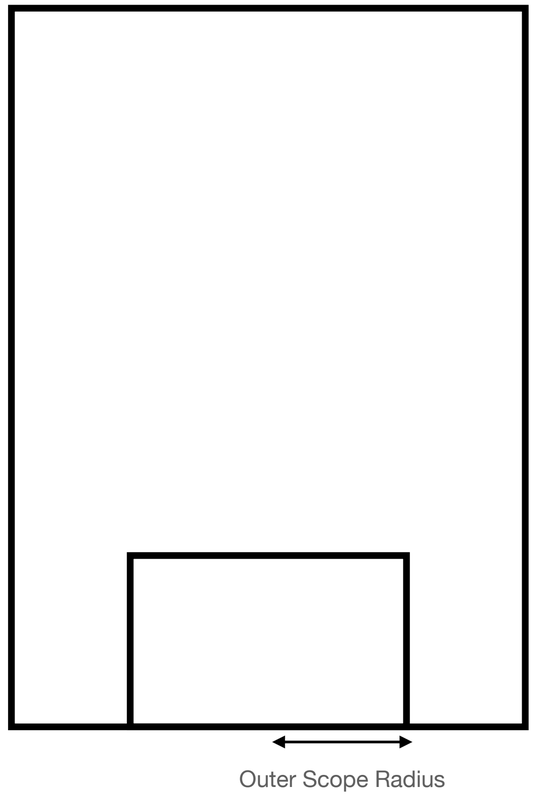
- ADMX future searches will take place inside large MRI magnet to be housed at Fermilab
- Low frequency working group led by Ben McAllister
- One area of interest is low mass range (100-500 MHz)
- Cavities are just too big to reach ~100 MHz
- Re-entrant cavity or novel design needed



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

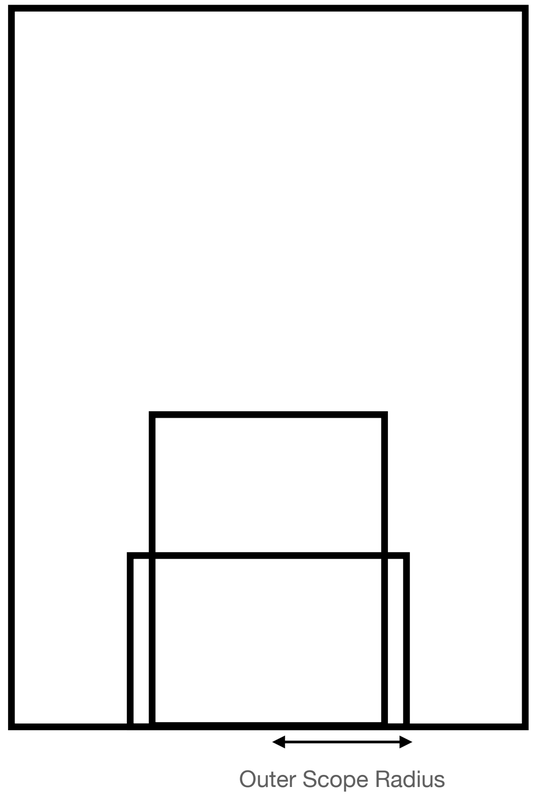
Low Frequency ADMX & ORGAN

- ADMX future searches will take place inside large MRI magnet to be housed at Fermilab
- Low frequency working group led by Ben McAllister
- One area of interest is low mass range (100-500 MHz)
- Cavities are just too big to reach ~100 MHz
- Re-entrant cavity or novel design needed



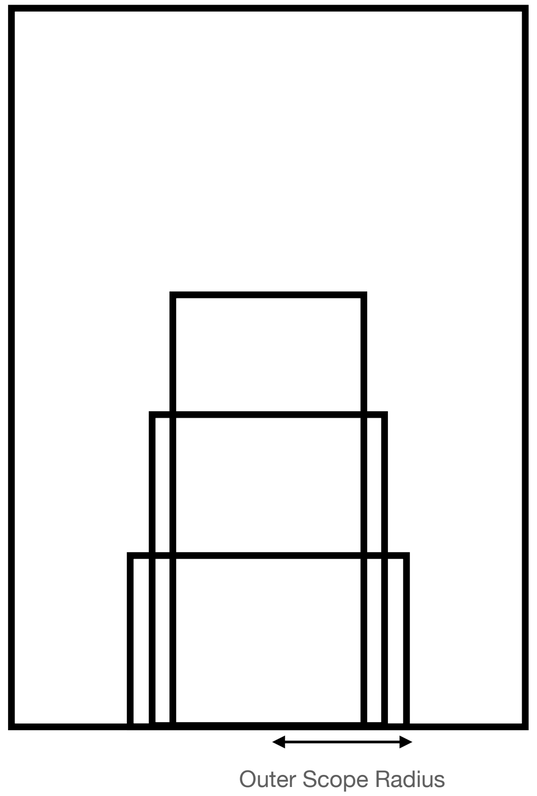
Low Frequency ADMX & ORGAN

- ADMX future searches will take place inside large MRI magnet to be housed at Fermilab
- Low frequency working group led by Ben McAllister
- One area of interest is low mass range (100-500 MHz)
- Cavities are just too big to reach ~100 MHz
- Re-entrant cavity or novel design needed



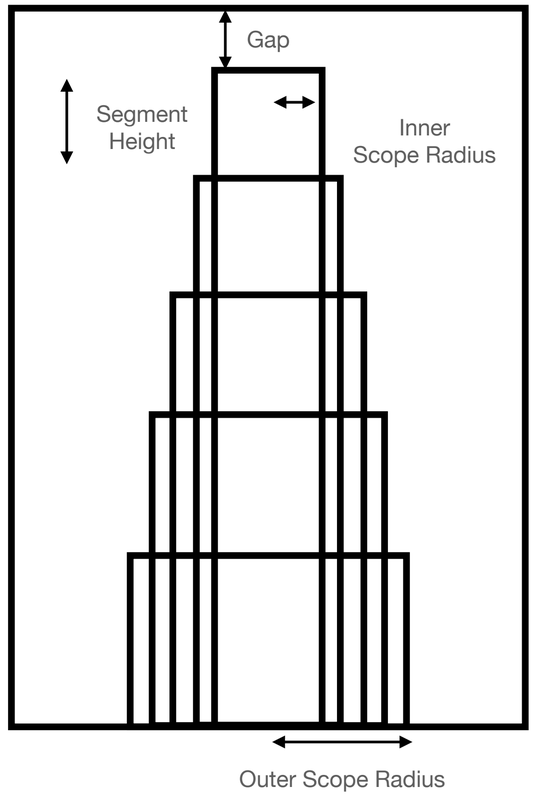
Low Frequency ADMX & ORGAN

- ADMX future searches will take place inside large MRI magnet to be housed at Fermilab
- Low frequency working group led by Ben McAllister
- One area of interest is low mass range (100-500 MHz)
- Cavities are just too big to reach ~100 MHz
- Re-entrant cavity or novel design needed



Low Frequency ADMX & ORGAN

- ADMX future searches will take place inside large MRI magnet to be housed at Fermilab
- Low frequency working group led by Ben McAllister
- One area of interest is low mass range (100-500 MHz)
- Cavities are just too big to reach ~100 MHz
- Re-entrant cavity or novel design needed



ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Questions?

Australian Government
Australian Research Council

National Partners

THE UNIVERSITY OF WESTERN AUSTRALIA

Australian National University

THE UNIVERSITY OF MELBOURNE

THE UNIVERSITY OF SYDNEY

THE UNIVERSITY of ADELAIDE

SWINBURNE UNIVERSITY OF TECHNOLOGY

Australian Government
Department of Defence

Australian Government
ANSTO

International Partners

UvA

UNI FREIBURG

Stockholm University

INFN

The University Of Sheffield.

HZDR

UNIVERSITY of WASHINGTON

Caltech