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1.Introduction

2.Overview of EDAMAME project

3.Recent result

4.Future prospect (Phase2, Phase3)

Axion search with Cavity haloscope

3

☆ Axion (*undiscovered*):

- Postulated to solve the strong CP problem in QCD.
- Leading cold dark matter candidate
- Converted into photons in strong magnetic field (Primakov Effect)

Target Frequency:

$m_a = \mathcal{O}(1 - 100) \mu\text{eV} \rightarrow \text{Frequency of } \gamma : \text{MHz-GHz}$

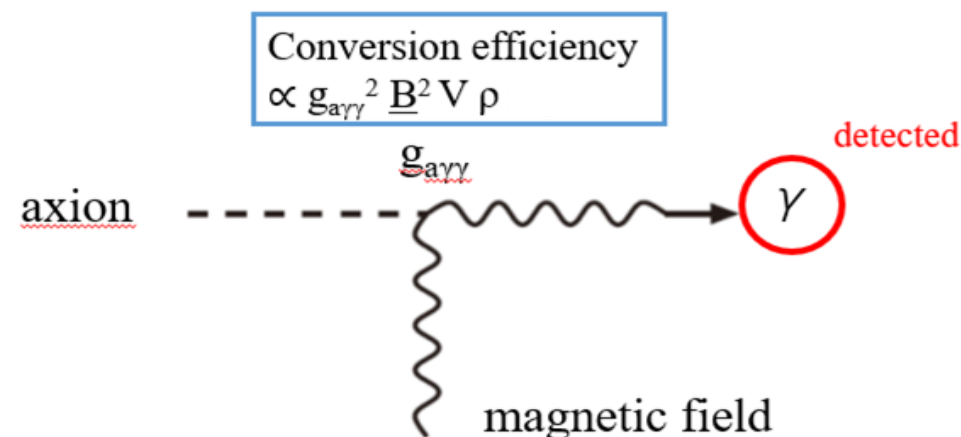
Extremely Weak Signal:

Expected power $\sim 10^{-24} \text{ W}$ (for KSVZ at $20 \mu\text{eV}$)
 $\rightarrow$ Resonantly amplify the signal using a cavity (High-Q).

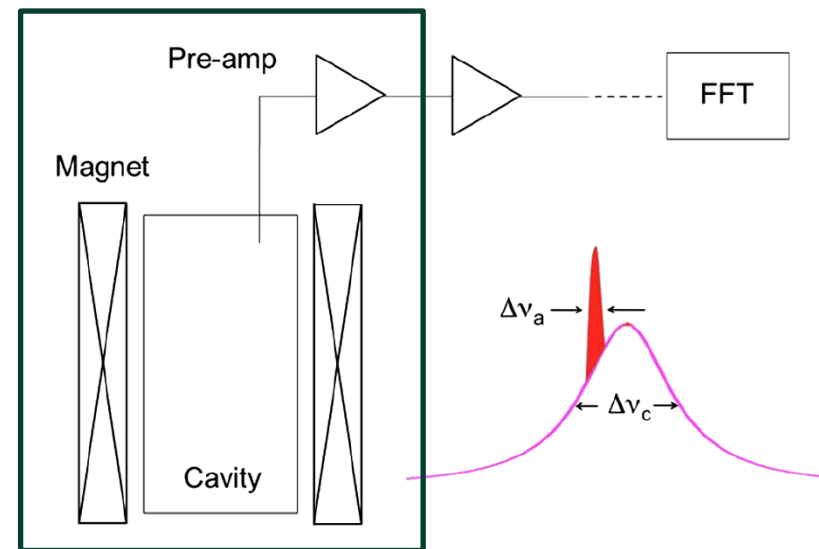
Main Background: Thermal noise.

$\rightarrow$ Cryogenic cooling system & ultra-low noise amplifiers

Experiments: ADMX, HAYSTAC, **EDAMAME**...



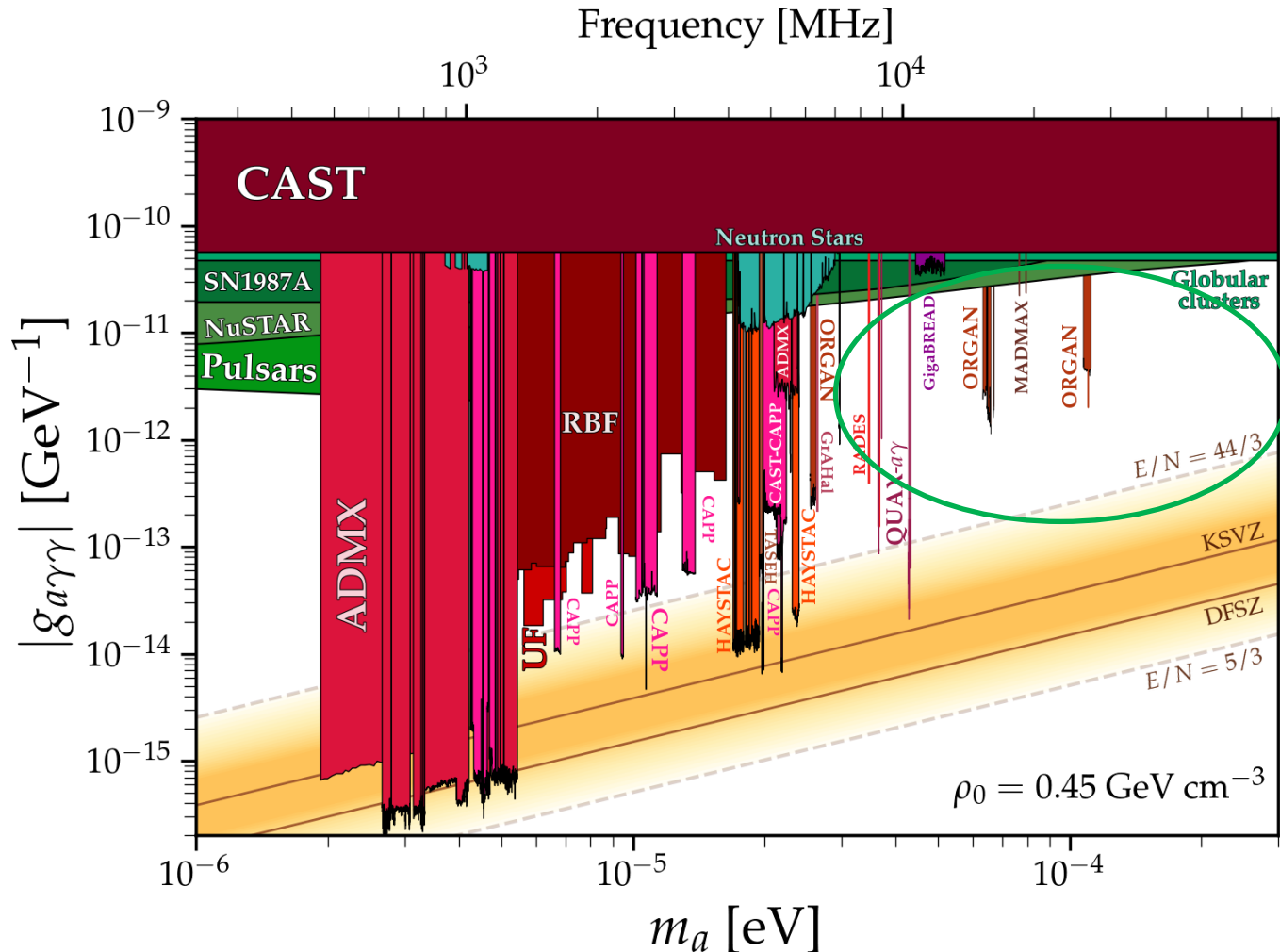
Cryostat



Current limit and our target

4

Ref) <https://cajohare.github.io/AxionLimits/>



Target mass: $\mathcal{O}(10 - 100) \mu\text{eV} \rightarrow \text{GHz region.}$

☆ **Theoretically Favored Region in some models**
Predicted by post-inflation scenarios
(e.g., topological defects).

☆ **Experimental Challenges in the GHz Regime**

1. Volume Penalty:

Requires smaller cavity sizes.
→ Reduces signal sensitivity ($P \propto V$).

2. Amplifier Development:

Requires specialized amplifiers capable of operating
in the GHz band under magnetic fields.

☆ **Advantages**

1. Compact detector system
2. Relaxed Standard Quantum Limit (0.5K @ 10GHz)

EDAMAME Project Timeline

5

2015 : Project started (spokesperson: Y. Kishimoto)

2017–2018 : Foundational Cavity R&D

2019 : Superconducting Magnet & Cryostat Installation

Jan. 2023 : Dark Photon Test Run ($B = 0$)

Nov. 2023

- Jan. 2024 : First Axion Pilot Run (9.0 T)

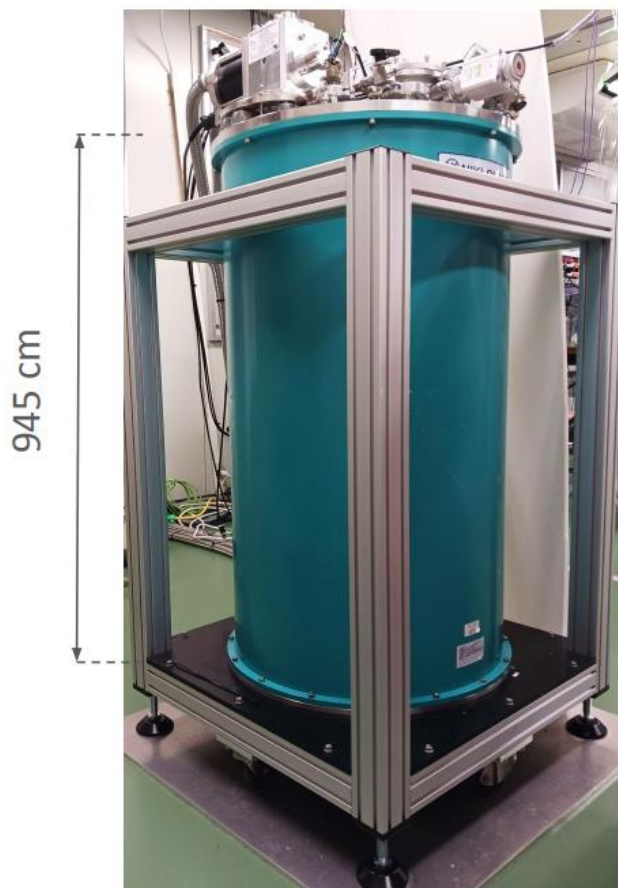
2025 : System development & Pilot run for Phase-2

May 2026 : Phase 1 Physics Run (Now)

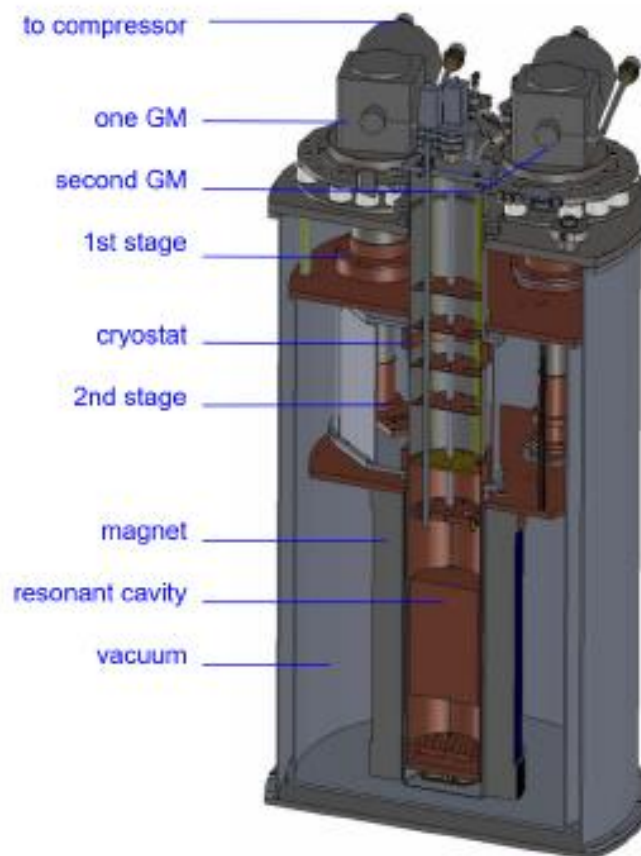
Support of
“UGRP”
地下稀事象

Detector setup of EDAMAME Phase 1

6



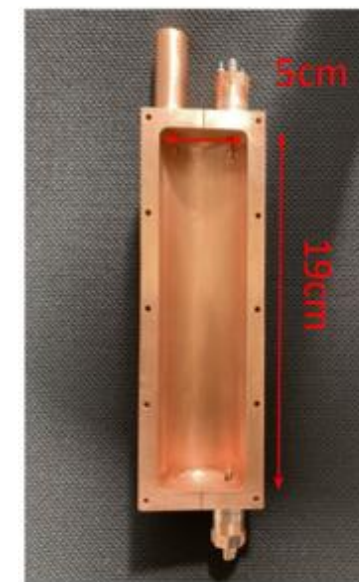
GM cryocooler : 1 W @4.2 K
T = 3.8 K @ no load



$$B_z = 9T$$



Cavity



Material: Copper
Volume (V): 371 cm³
Geometrical factor : 0.6907
Resonant Frequency (f_r):
4.6 GHz(TM₀₁₀ mode)
Corresponding axion mass: $m_a \approx 19 \mu\text{eV}$
Tuning Mechanism:
The resonant frequency can be tuned by inserting a polyethylene rod.

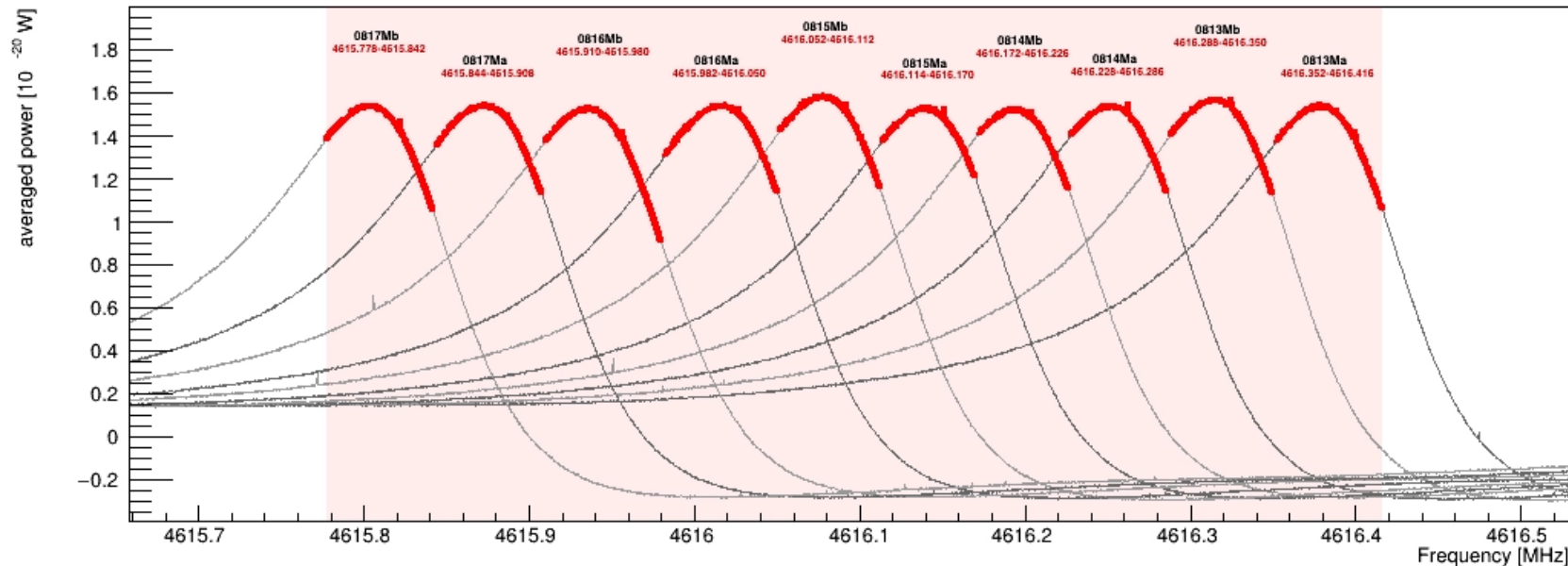
Data summary

7

- * Period: Aug 13 – Aug 28, 2026
- * Cavity tuning: 35 setups,
 $F_r = 4616.573 \rightarrow 4614.491$ MHz ($19.084 - 19.092$ μeV)
Integration time : ~ 8 h per setup

- * Spectrum analyzer:
FFT type, 2.5 MHz span captured at once 32,769 points $\rightarrow$ raw bin width 76.3 Hz, RBW = 300 Hz
Traces: 20 s integration each, $\times 1,540$ traces per setup

zoom, band-edge floors subtracted so the spectra sit at the same height

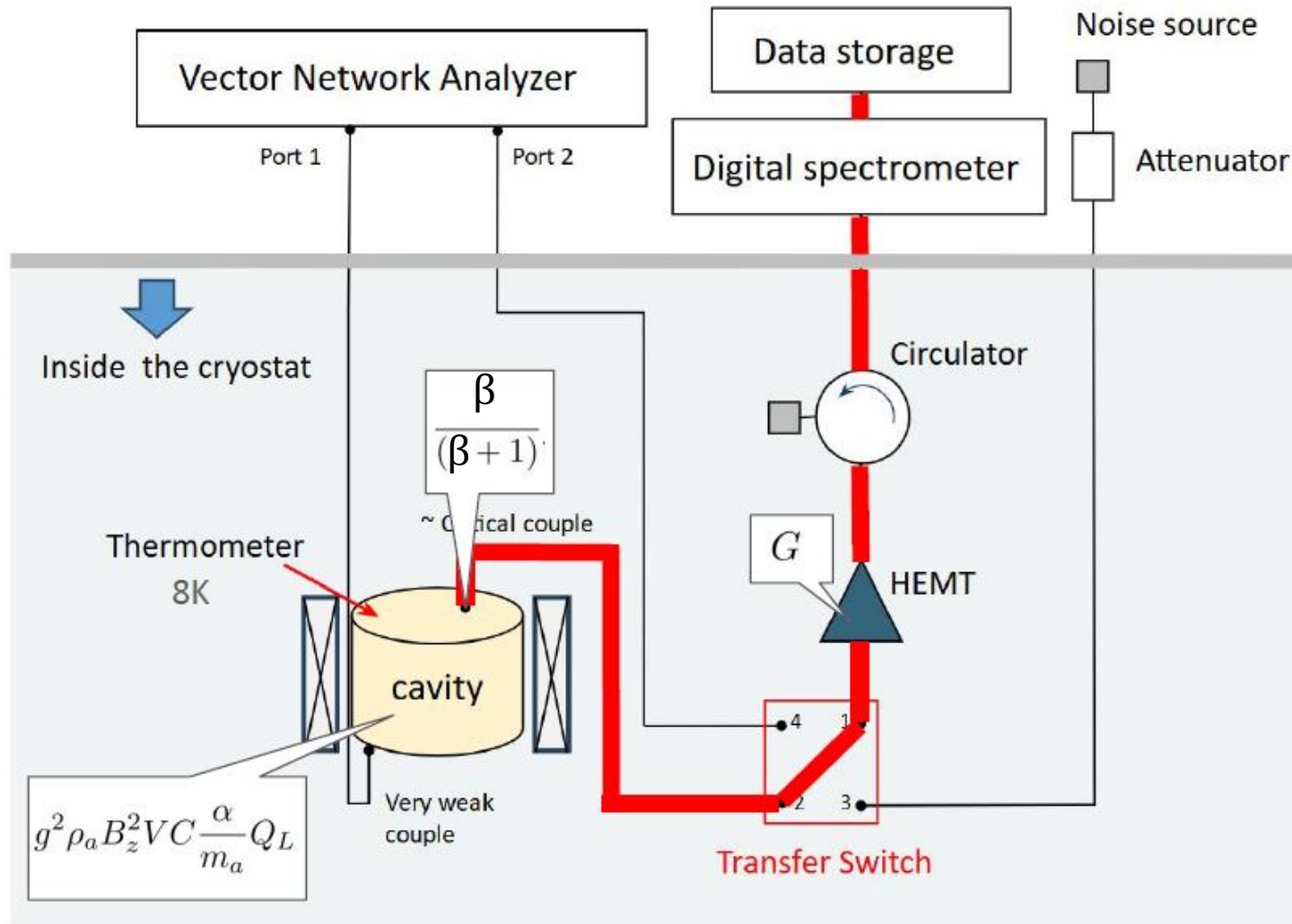


Dataset in this report

- * Datasets: Aug 13 – Aug 17 (10 setups)
80% of data retained
(unstable cavity conditions excluded)
- * Signal search near each cavity resonance,
2 kHz scan step
- * Frequency coverage:
4615.772 – 4616.412 MHz (640 kHz)
 - Axion mass coverage:
19.0893 – 19.0920 μeV (2.65 neV)

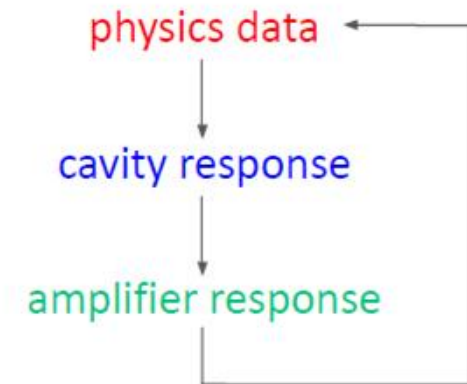
Schematic view of the system

8



SA : MS2840A (Anritsu)
VNA : E5063A (KEYSIGHT)

Data acquisition steps

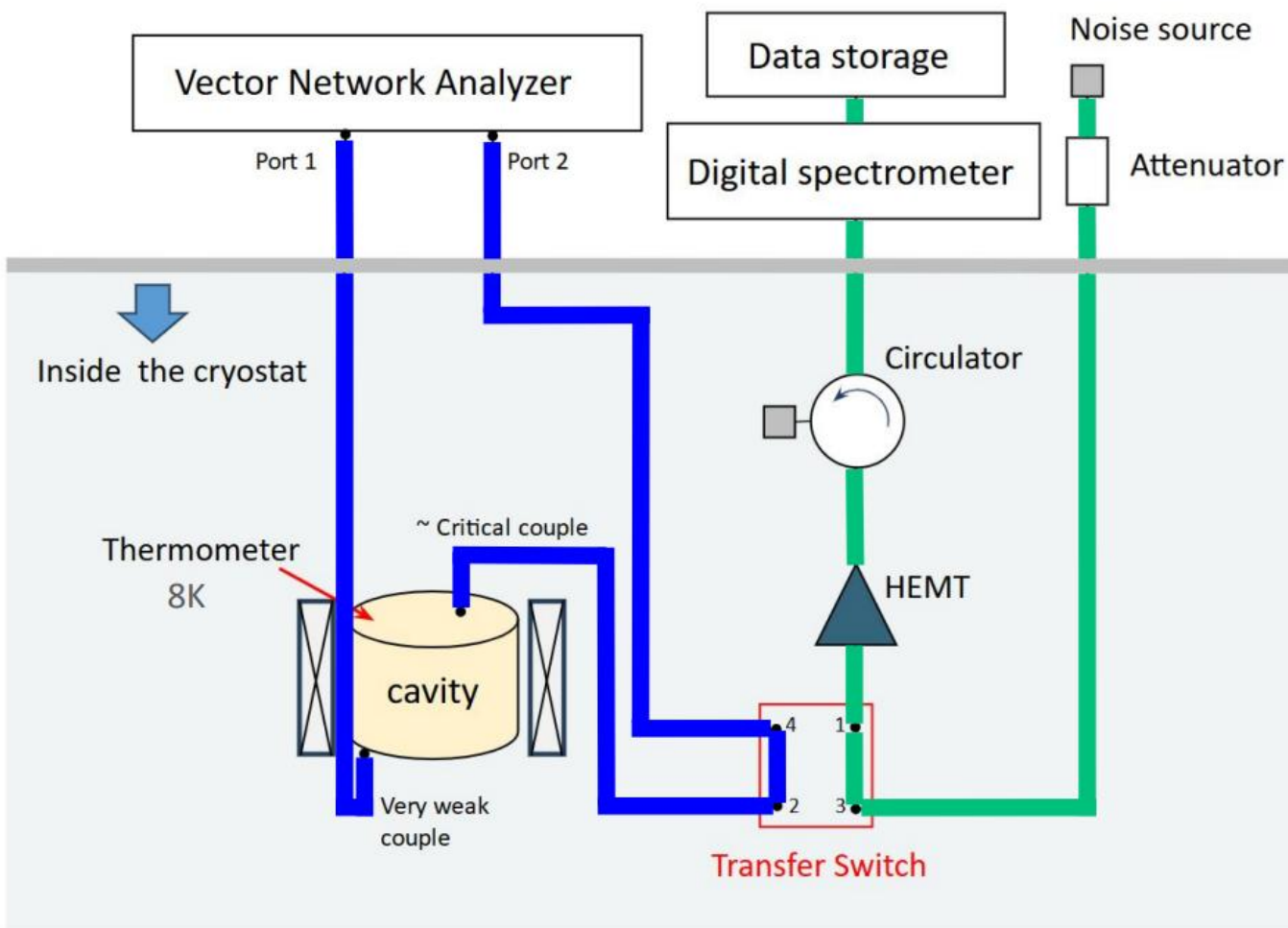


Total axion power

$$P = \frac{\beta G}{(\beta + 1)} g^2 \rho_a B_z^2 V C \frac{\alpha}{m_a} Q_L$$

Calibration system

9



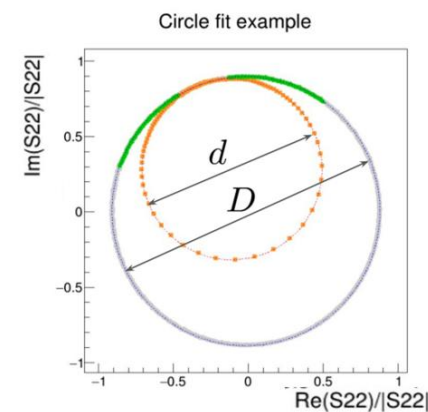
$$P = \kappa G \left[g^2 \rho_a B_z^2 V C \frac{\alpha}{m_a} Q_L \right]$$

1. Amplifier Response

← Determination from Noise source

2. Antenna Coupling

← Reflection ($|S_{22}|$) of cavity

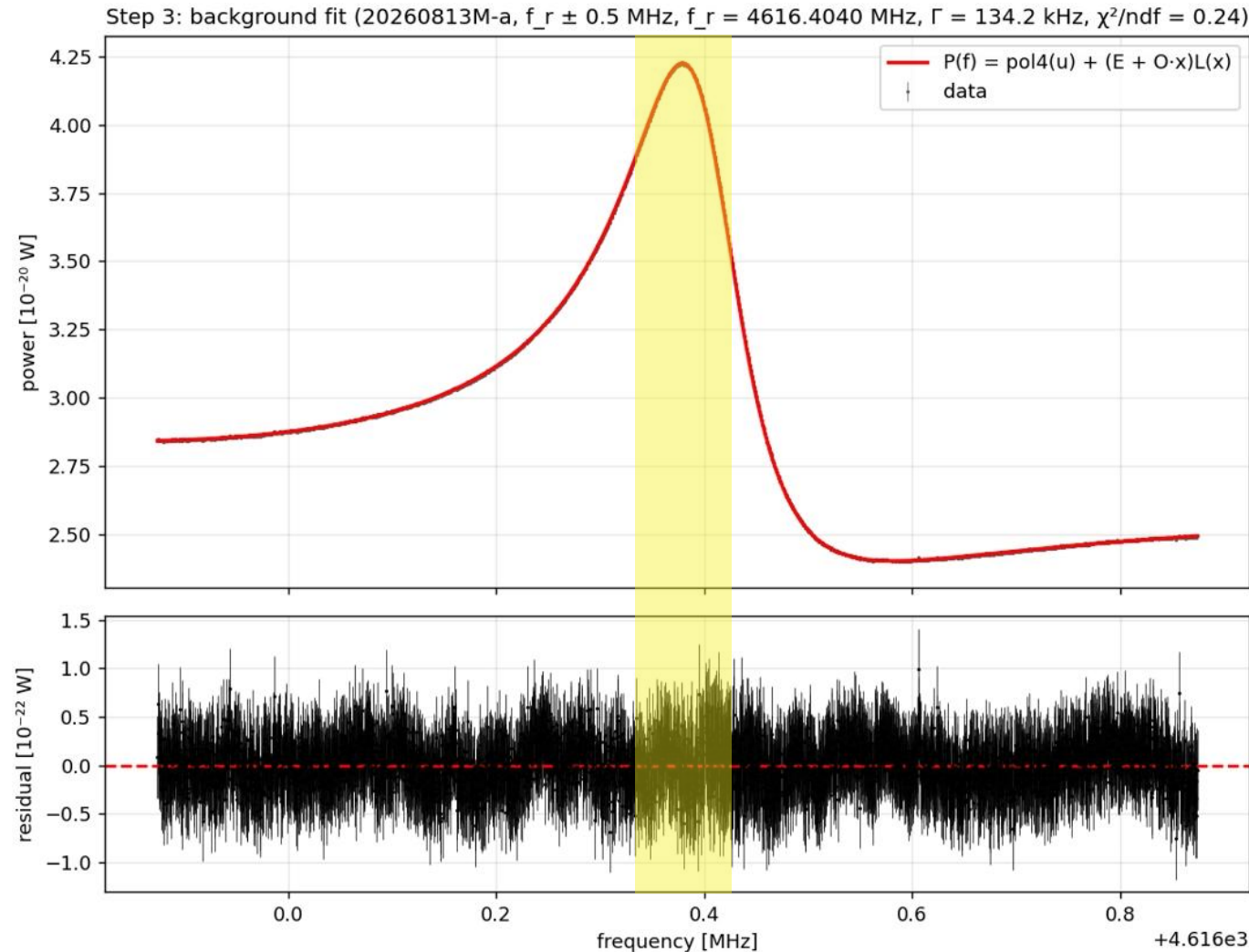


Circle fitting
in order to estimate:

$$\frac{\kappa}{\kappa + 1} = \frac{d}{D}$$

Measurement of Power spectrum and BG fit

10



Amplifier noise

Lorentz function (cavity response)

$$P(f) = \sum_{i=0}^4 b_i u^i + (E + O \cdot x) \cdot L(x)$$

Cavity parameter
 $f_r \sim 4.6\text{GHz}$
 $\Gamma \sim 134\text{ kHz}$
 $Q \sim 34000$

Interference with the reflection of amplifier

Bin errors: trace-to-trace scatter, rescaled by off-resonance pull width (effective error scale ≈ 2.4 , dominated by residual ripple)

Signal Search Method

11

Hypothesis test at each scan frequency

- H0 (background only): pol1
- H1 (background + signal): pol1 + μ · axion signal

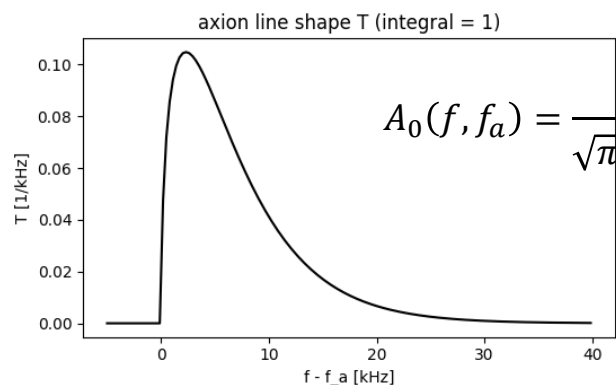
$$\Delta\chi^2 = \chi^2_{\text{BG}} - \chi^2_{\text{BG+Sig}}$$



Large $\Delta\chi^2 \rightarrow$ candidate;

$$90\% \text{ CL: } \chi^2(\mu_{90}) - \chi^2(\hat{\mu}) = 1.64$$

Axion signal function (Maxwell-Boltzman distribution)

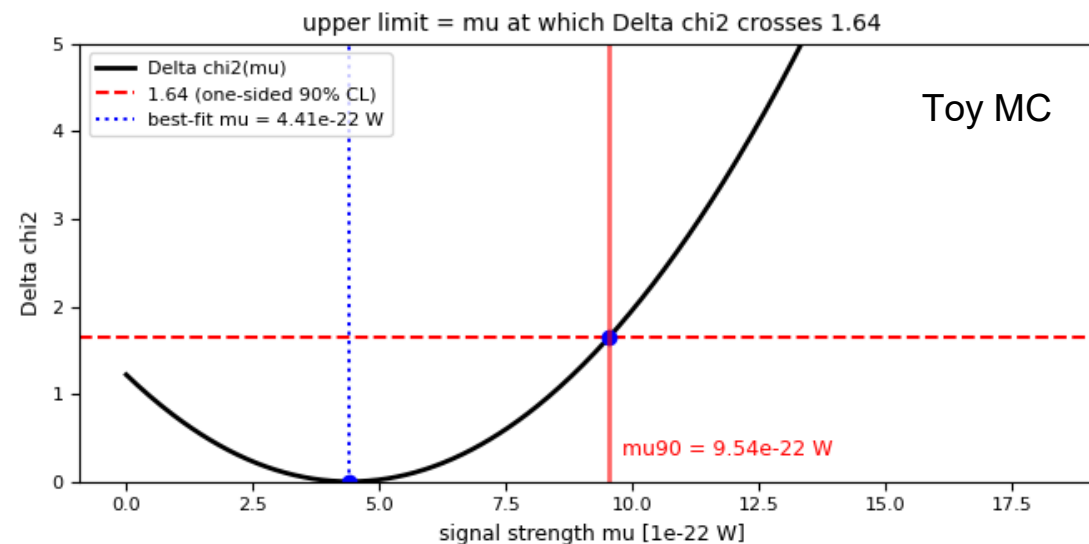
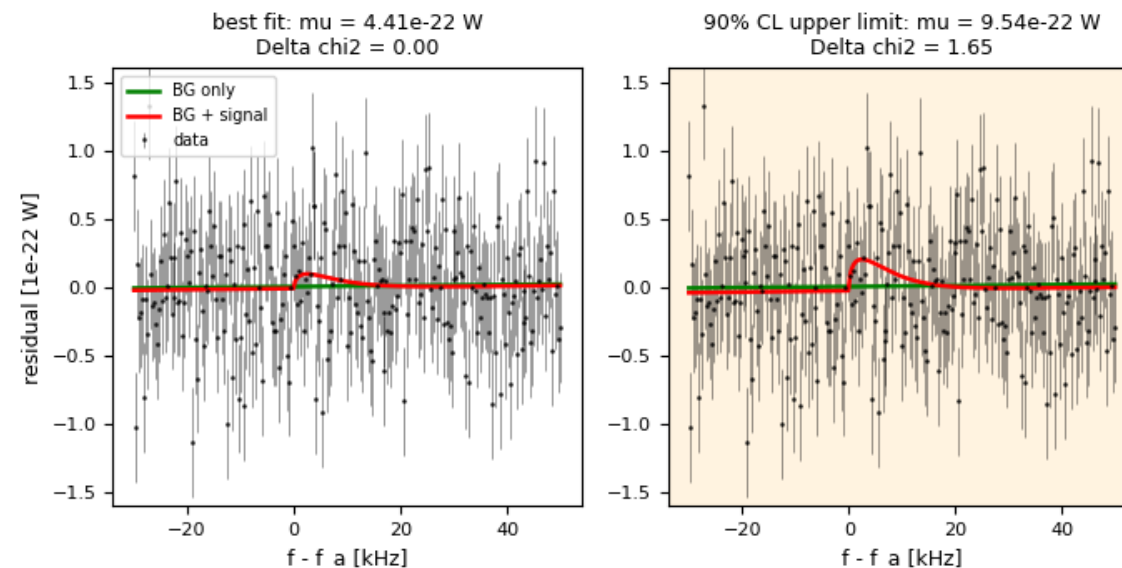


$$A_0(f, f_a) = \frac{2}{\sqrt{\pi} w_a^{3/2}} \sqrt{f - f_a} \exp\left(-\frac{f - f_a}{w_a}\right) L(f)$$

$$w_a = f_a \cdot \langle v^2 \rangle / c^2 \approx 4.6 \text{ kHz}$$

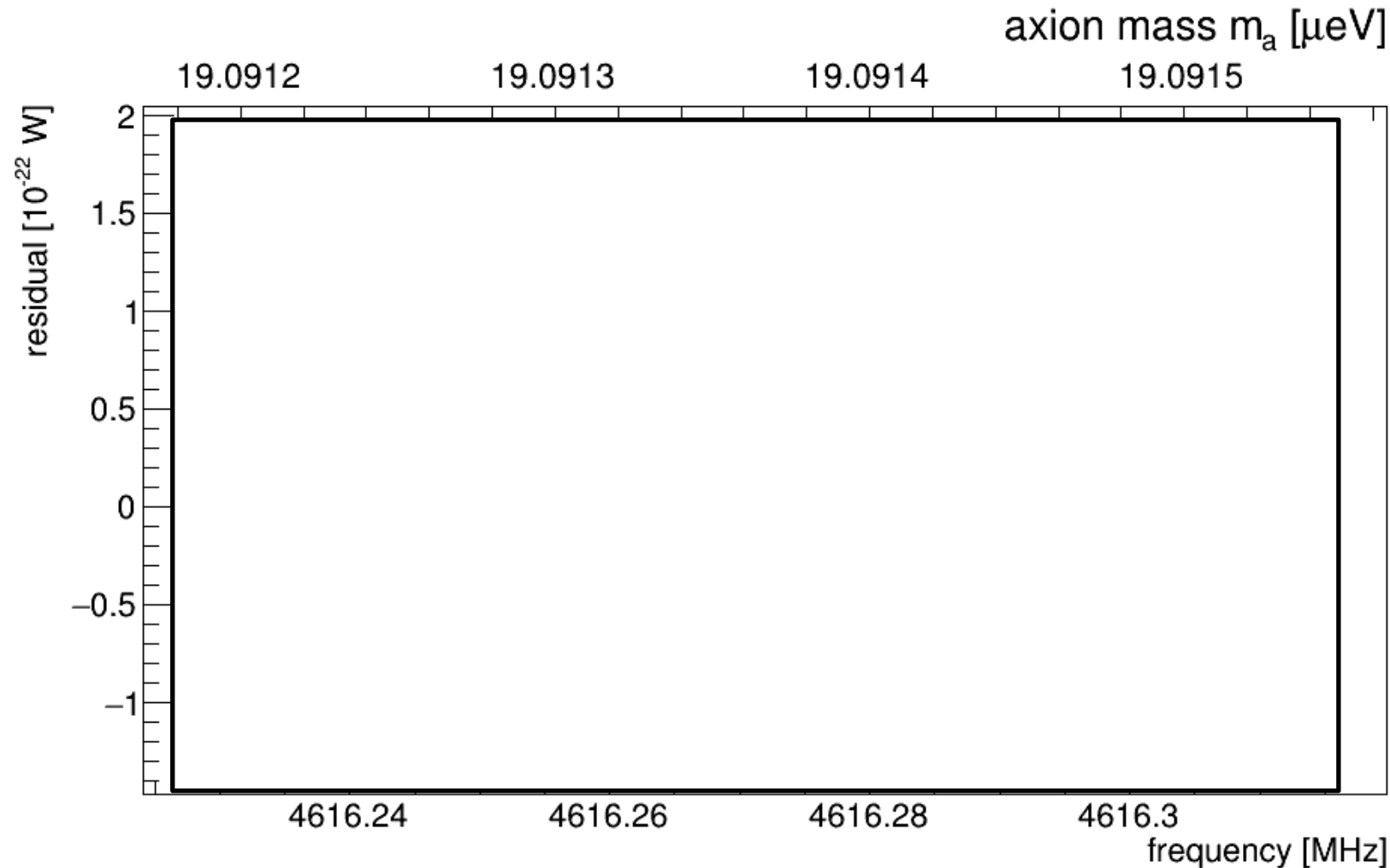
$$v_a \sim 424 \text{ km/s}$$

Cavity effect



The signal candidate (largest $\Delta\chi^2$)

12



$\Delta\chi^2 \approx 5.8$ ($f_a = 4616.262$ MHz)
 $Z_{\text{local}} = 2.4\sigma$,

$p_{\text{local}} = 8.2 \times 10^{-3}$

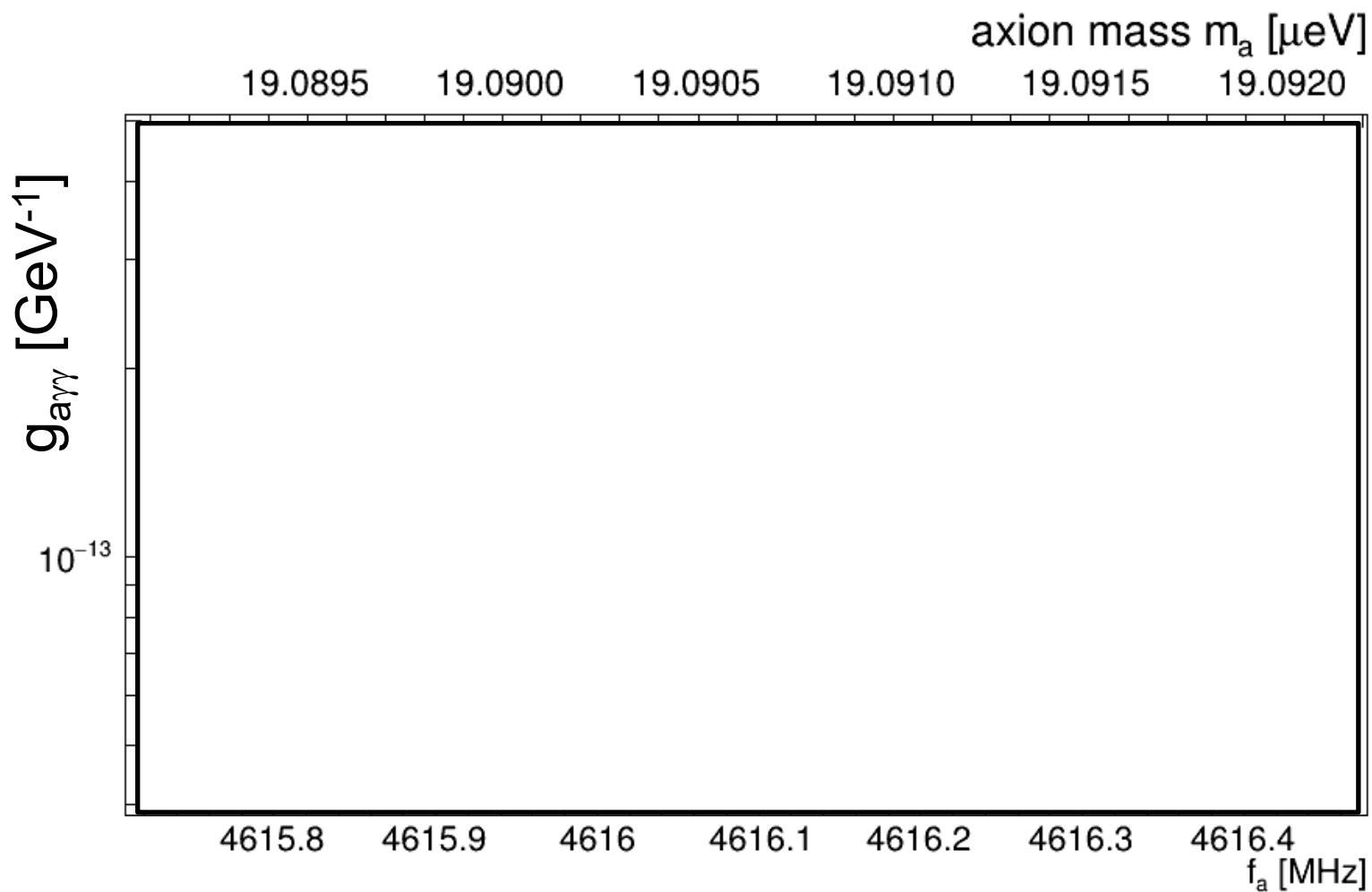
$p_{\text{global}} \approx 0.75$
(after LEE correction)

→ Statistical fluctuation

4616.2620 MHz ($m_a = 19.09131$ μeV)

Upper Limit plot of $g_{a\gamma\gamma}$ (90%CL)

13



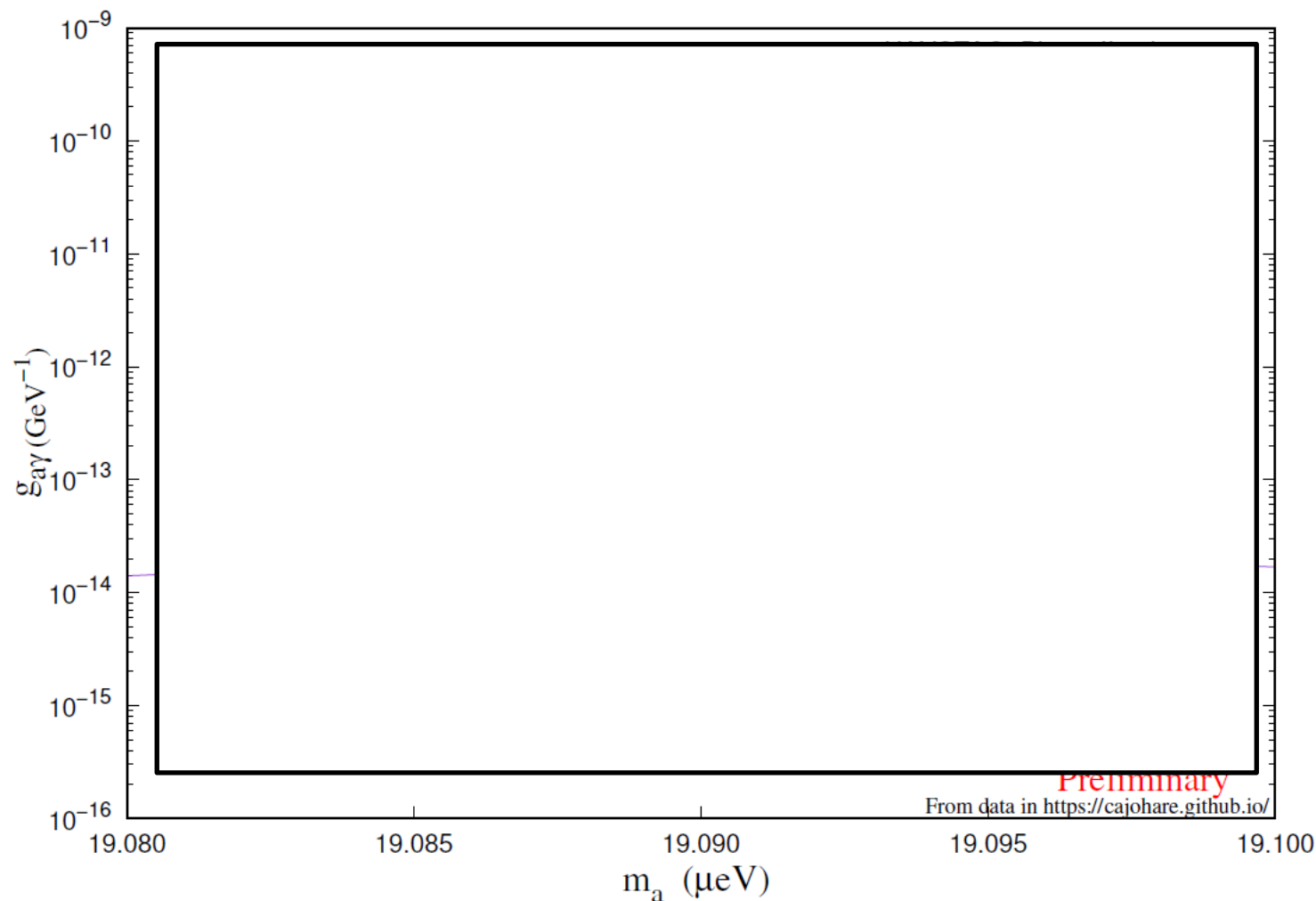
$$P = \kappa G g^2 \rho_a B_z^2 V C \frac{\alpha}{m_a} Q_L$$

$B=9\text{T}$
 $V=371\text{ cm}^3$
 $\kappa=0.479$
 $C=0.6907$
 $G \sim 5000$

Note)
- Systematic uncertainties
on B, C, V, κ not yet included.

Comparison with HAYSTAC-Phase II

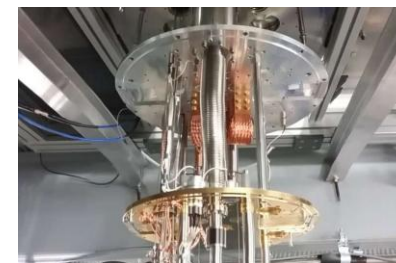
14



Haloscope At Yale Sensitive To Axion CDM (HAYSTAC) Experiment

Phys. Rev. Lett. 134, 151006
– Published 18 April, 2025

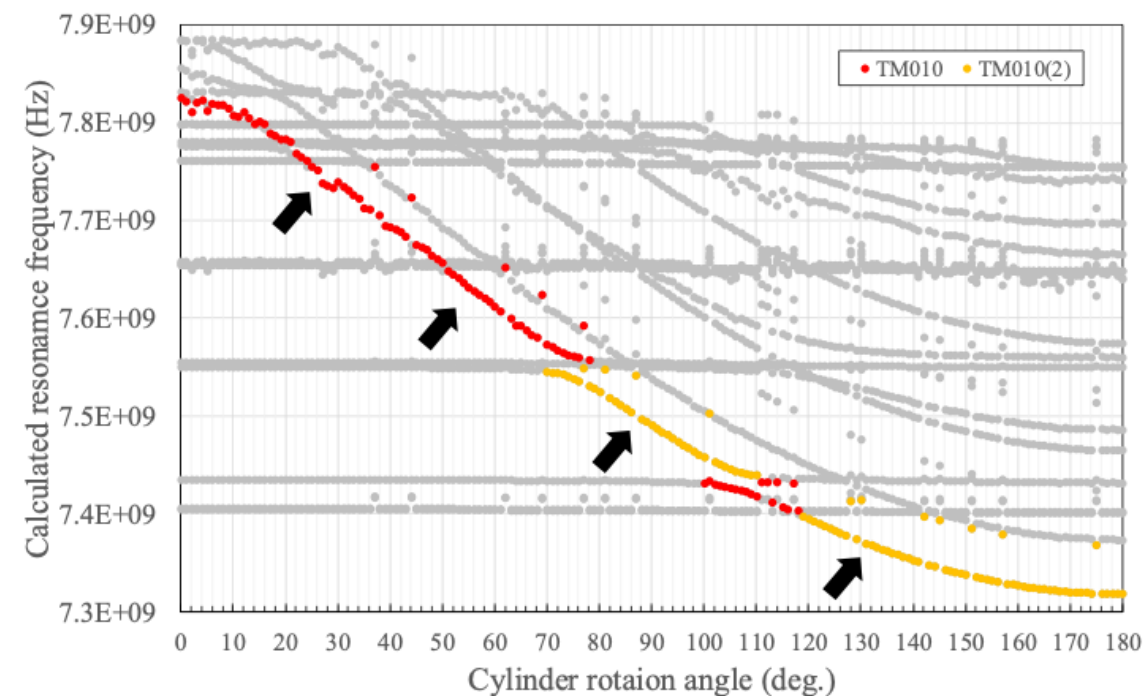
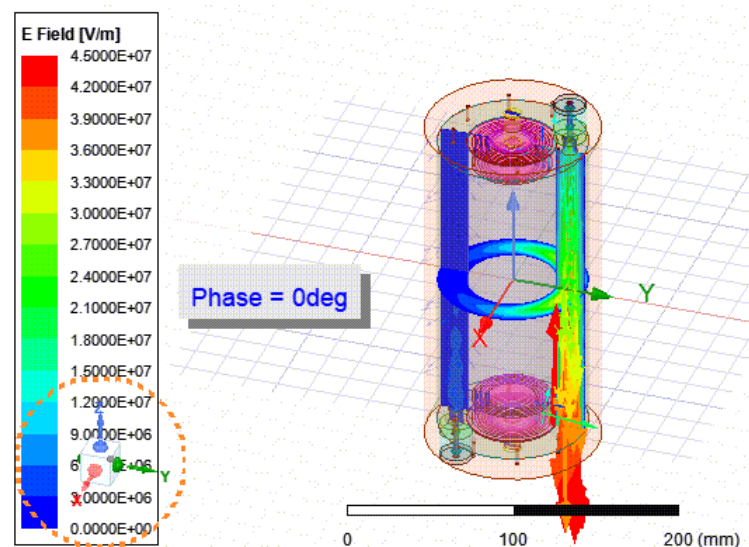
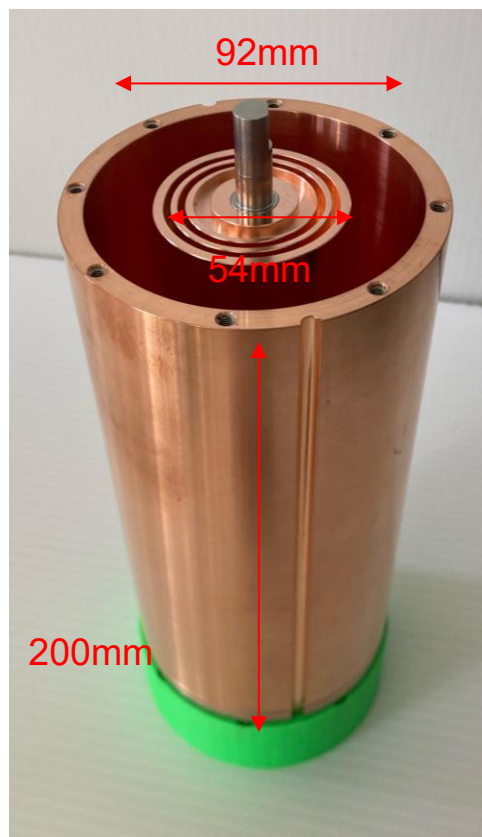
- $m_a = 17.28\text{--}18.44 \mu\text{eV}$
 $g_{a\gamma} \geq 2.75 \times g_{a\gamma}^{\text{KSVZ}}$
- $m_a = 18.71\text{--}19.46 \mu\text{eV}$
 $g_{a\gamma} \geq 2.96 \times g_{a\gamma}^{\text{KSVZ}}$



Ref) <https://phys.org/news/2025-05-results-haystac-phase-ii-dark.html/>

New Cavity for higher frequency

15



Volume = 1330 cm³ (x 3.5 of current cavity)

7.35 – 7.9 GHz

→ 30.4 – 32.67 μ eV

3 Strategies to enhance sensitivity (upto KSVZ) in a wide search region

1. Magnet System (9T360-CSM at HFLMS):

9 T magnetic field generated by NbTi & Nb₃Sn superconducting coils in a 360 mm room-temperature bore.

2. Cryogenic Sample Volume:

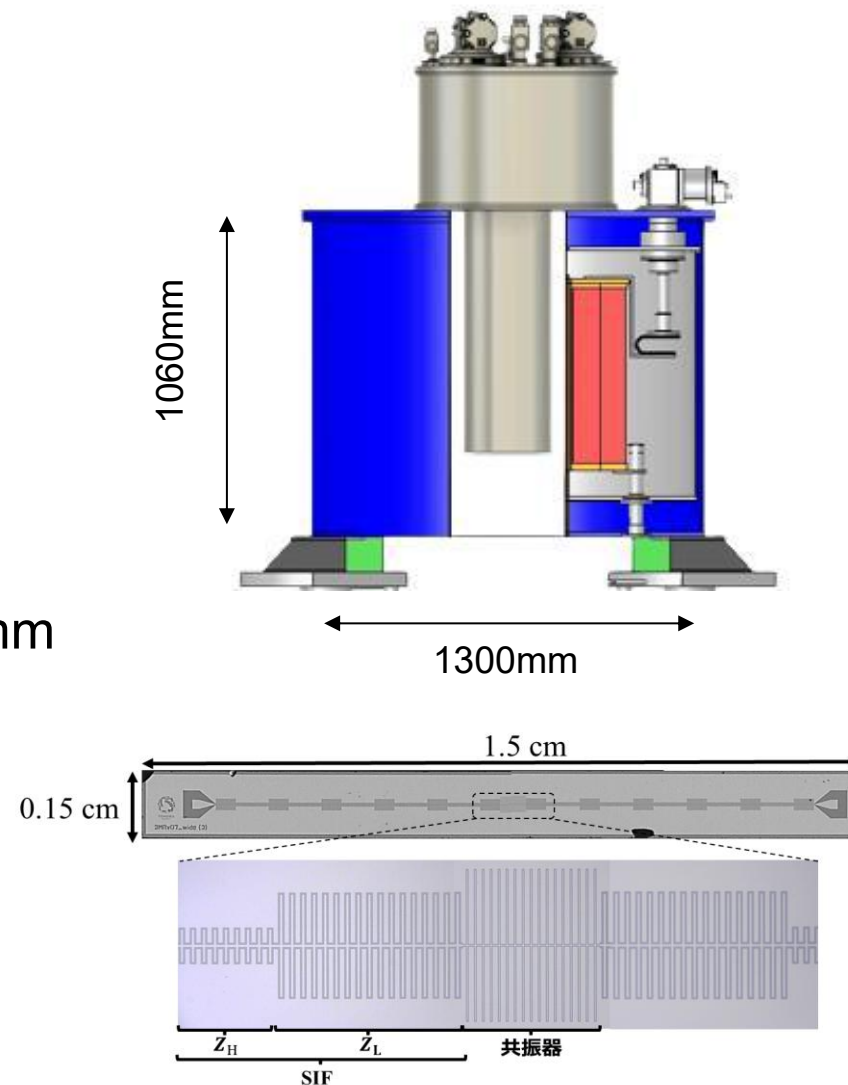
Superfluid He refrigerator achieving ~2 K for a $\phi 280$ mm $\times$ L220 mm sample space.

3. Low-Noise amplifier:

Kinetic Inductance Parametric Amplifier, KIPA
placed at a 2 K low-field stage

Band width: 7.675 – 13GHz.

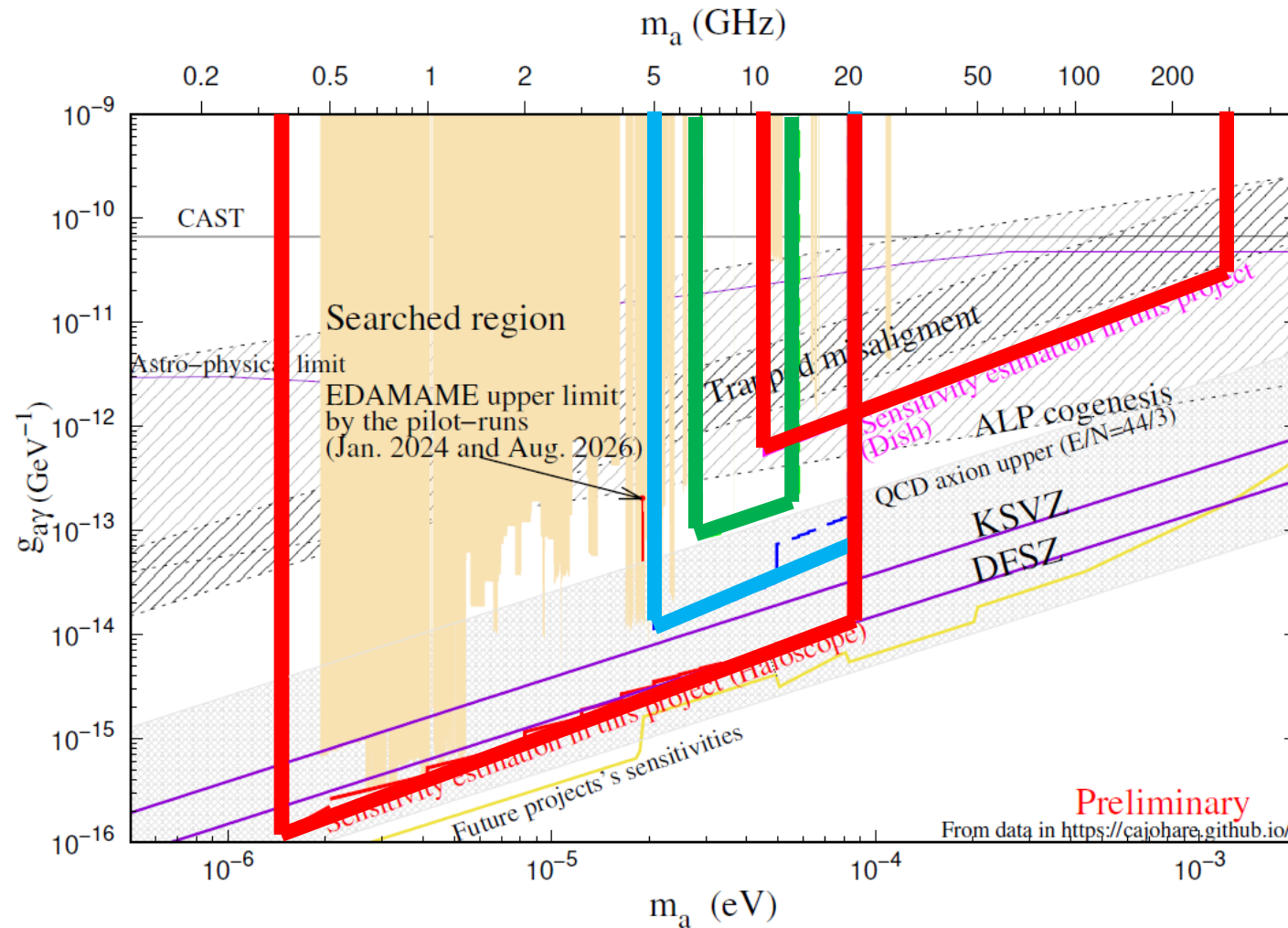
SQL at 10mK, 6T



2027~

Future goal

17



☆ Phase 1 (2026 -)

☆ Phase 2 (2027 -)

Target Mass: $m_a = 10 - 40 \mu\text{eV}$

Target Sensitivity: KSVZ line

☆ Phase 3 (Future)

Approach:

Long-term measurement, $B=13\text{T}$

Method:

Haloscope + Dish antenna technique

Target Mass: $m_a = 1 - 100 \mu\text{eV}$

Target Sensitivity: DFSZ Model

- **EDAMAME**: axion haloscope search at Tohoku university, targeting 10–100 μeV
- Phase 1 physics run ongoing (May 2026–):
B=9 T, 4.6 GHz copper cavity, tuning scan of 35 setups
- First results from 10 datasets (Aug 13–17):
 $m_a = 19.0893\text{--}19.0920 \mu\text{eV}$ (2.65 neV) scanned
no significant excess
90% CL upper limit: $g_{a\gamma\gamma} \sim 1.3 \times 10^{-13} \text{ GeV}^{-1}$ (preliminary)
- Next: Search experiment with 7GHz cavity ($m_a \sim 30\mu\text{eV}$)
 $\Rightarrow$ Phase 2 (2027–): 10–40 μeV at KSVZ sensitivity with new large cavity + KIPA

EDAMAME project just started physics measurement. Collaboration is welcome!