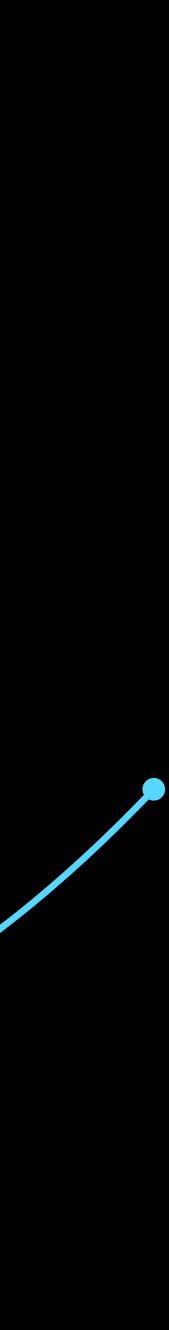
AXIONS AND WAVE-LIKE DARK MATTER

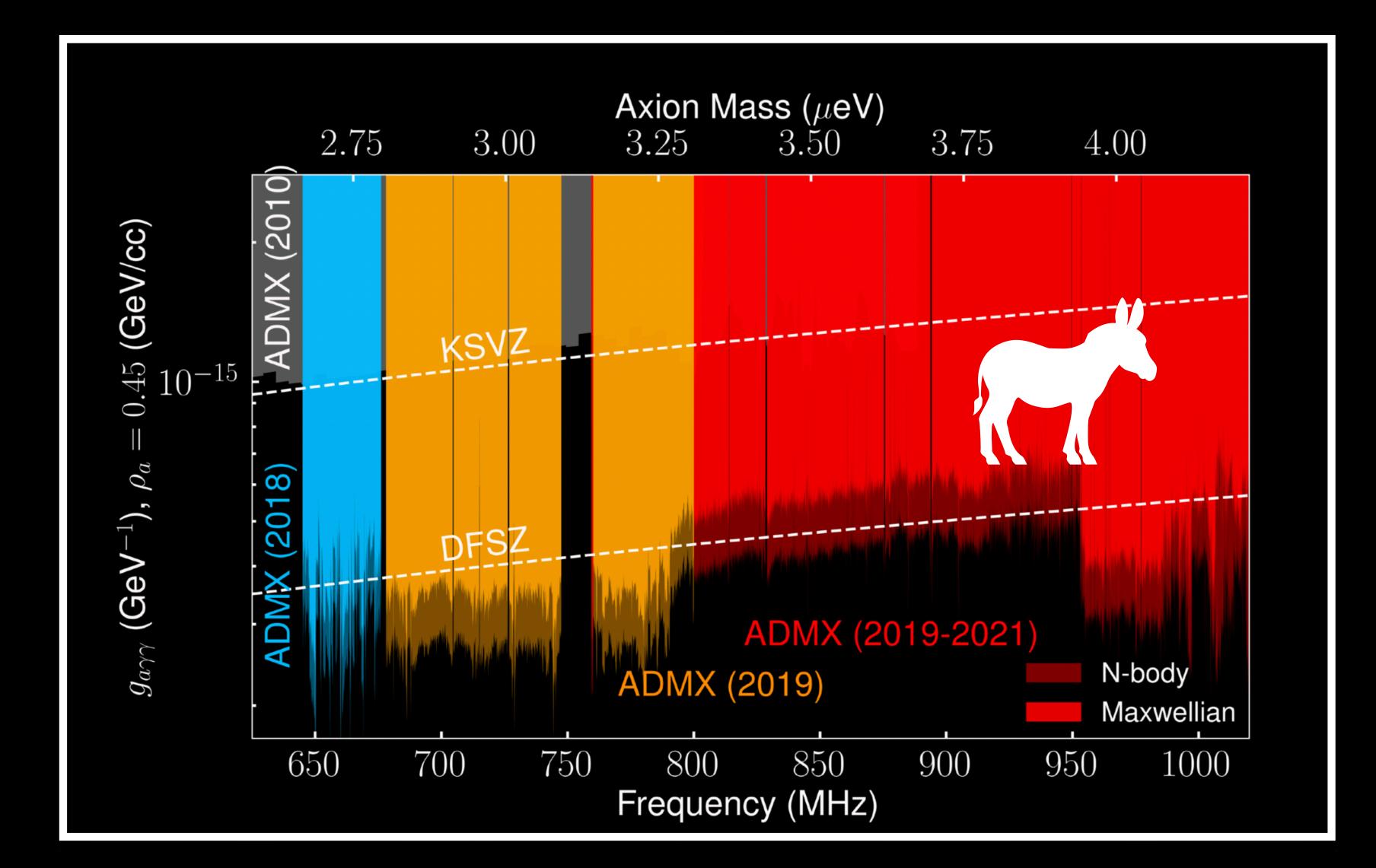
••••••

DESY WORKSHOP

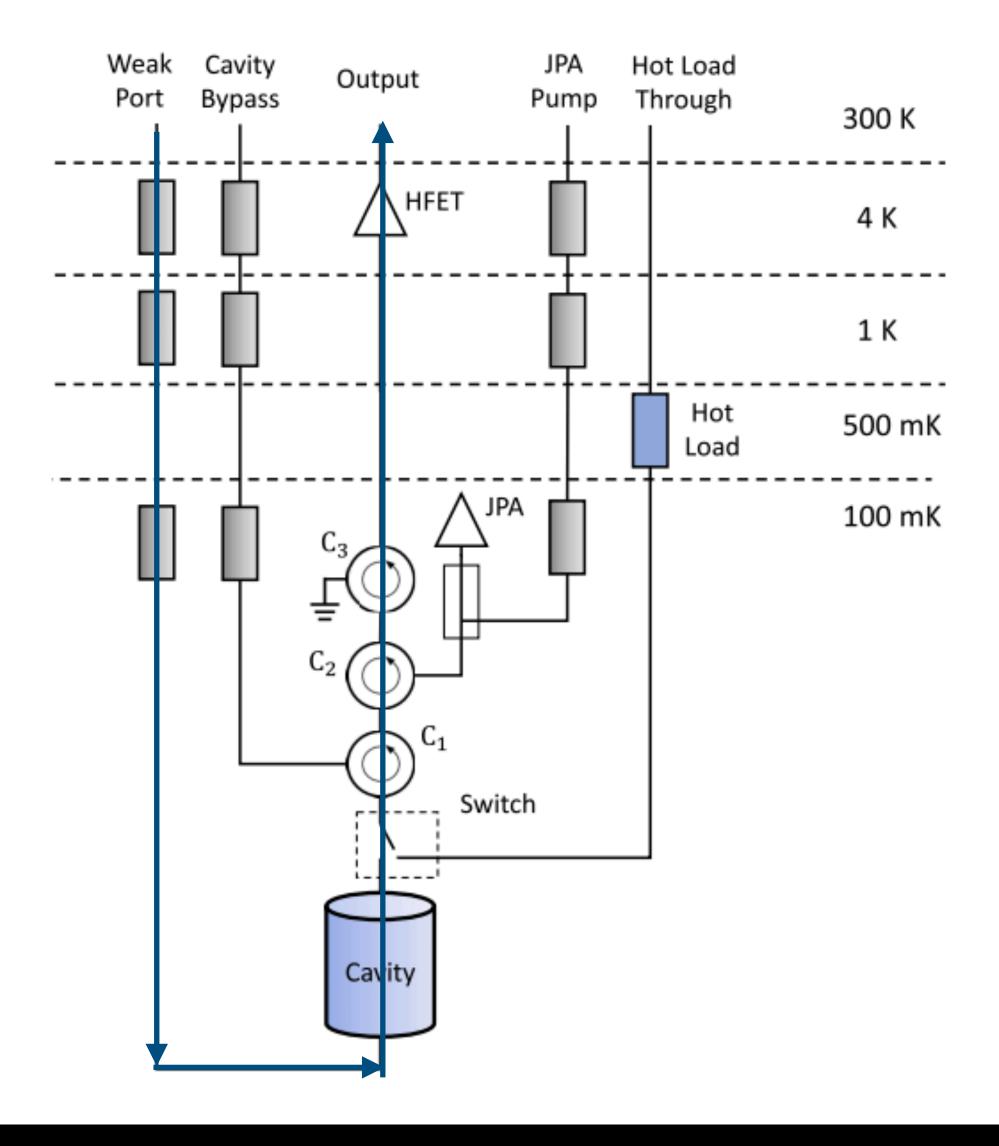
CHELSEA BARTRAM 2024



Pin-the-tail-on-the-axion-mass?





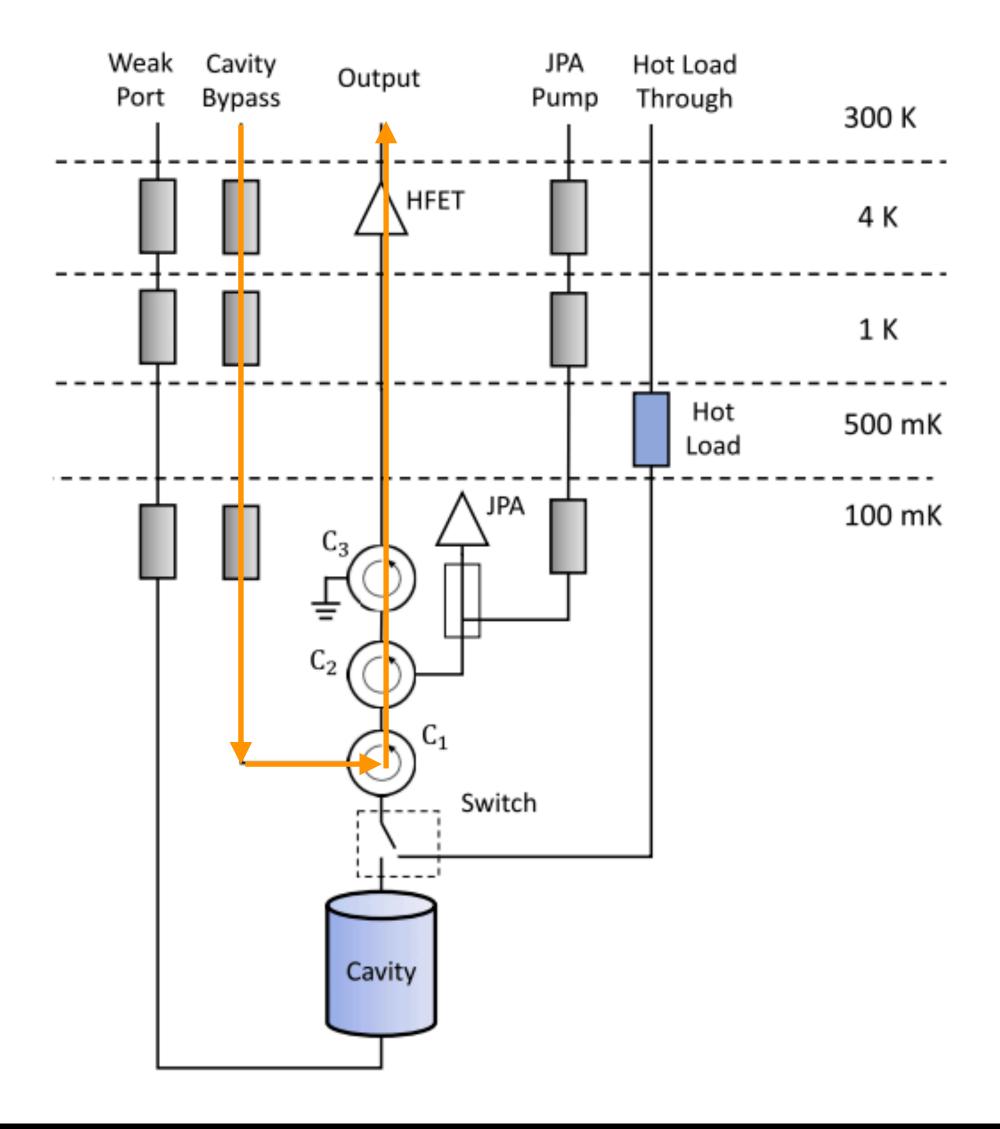


Important characterization measurements

• Transmission Measurements

- Reflection Measurements
- System noise measurements
- Synthetic injections





Important characterization measurements

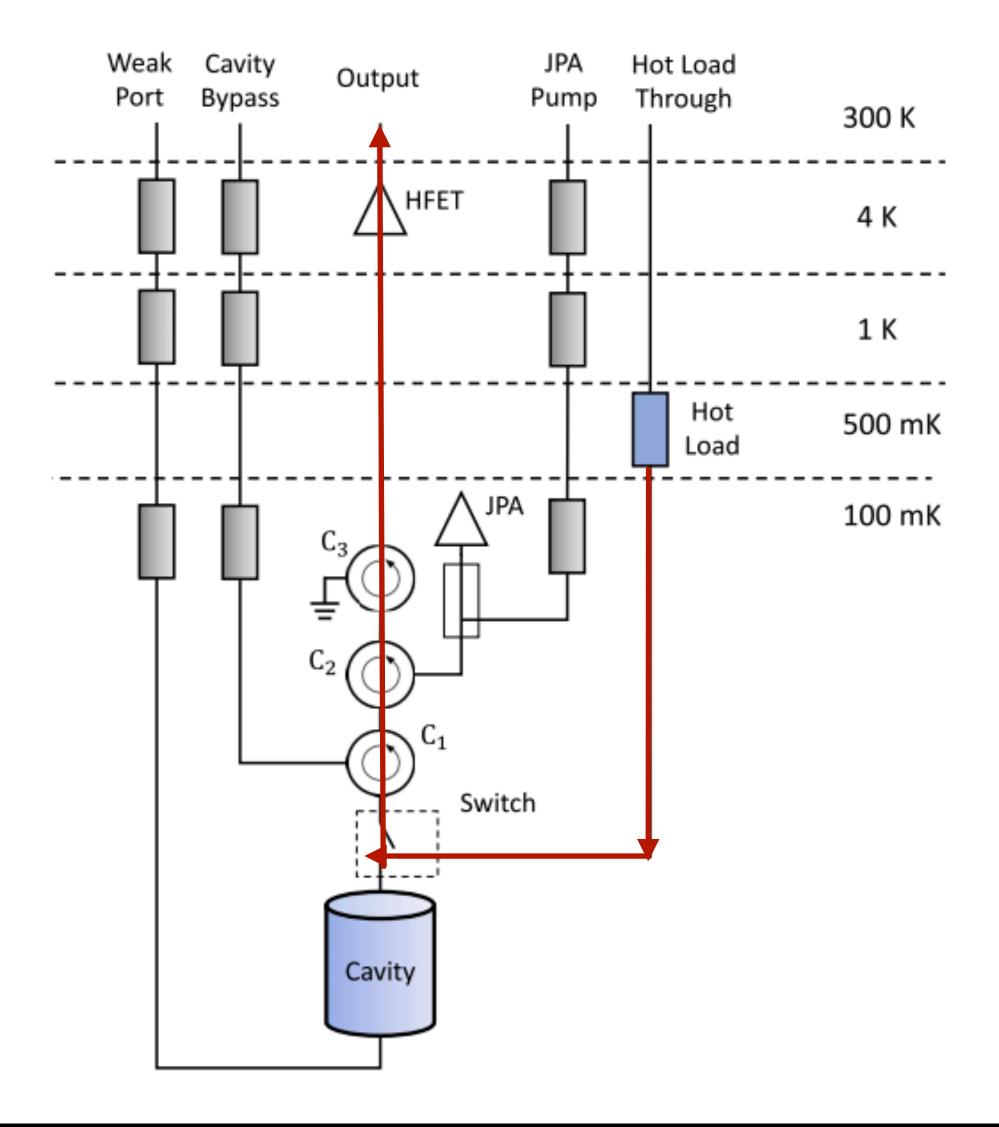
Transmission Measurements

Reflection Measurements

• System noise measurements

• Synthetic injections





Important characterization measurements

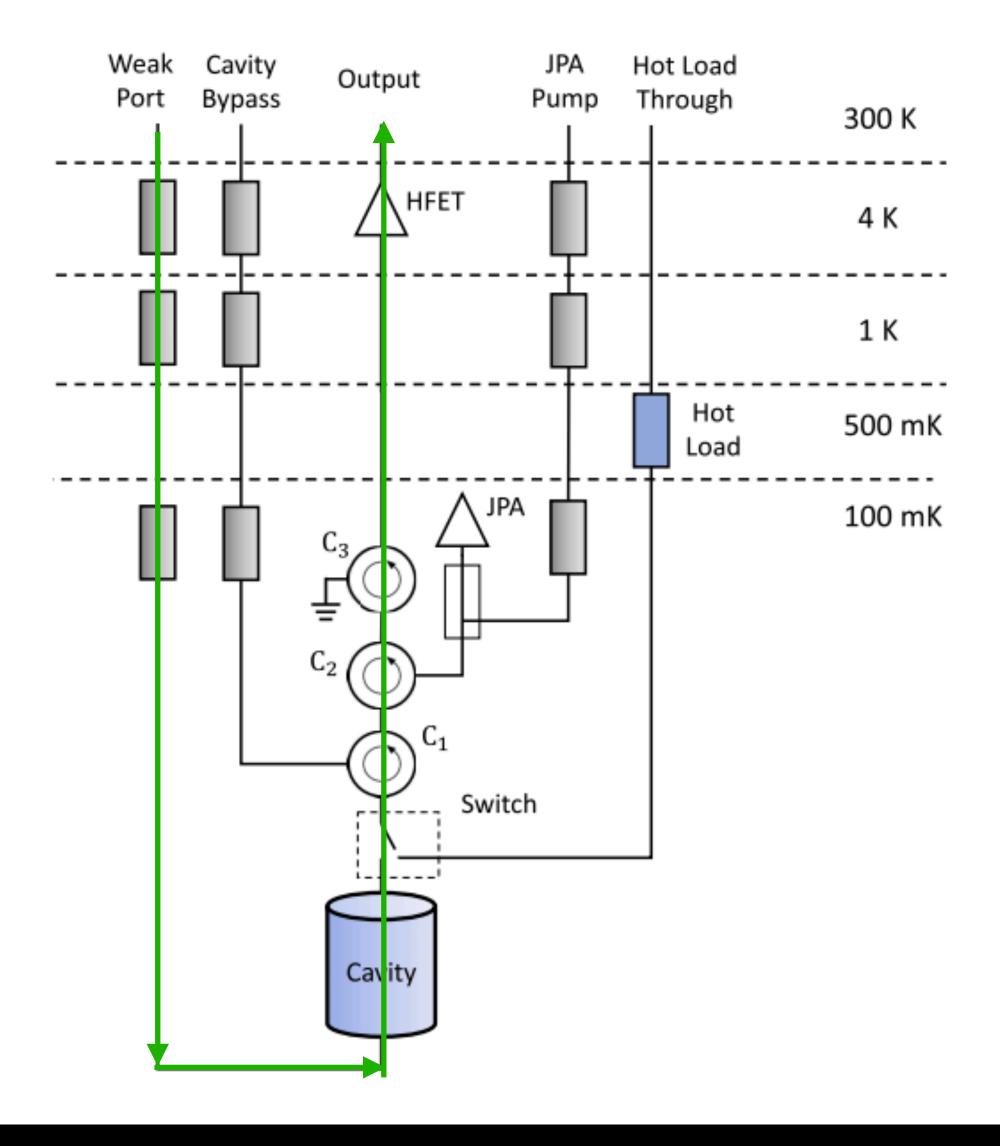
• Transmission Measurements

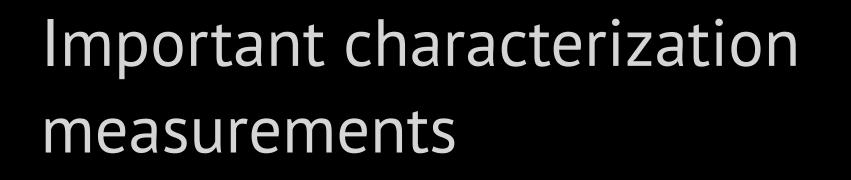
• Reflection Measurements

• System noise measurements

Synthetic injections









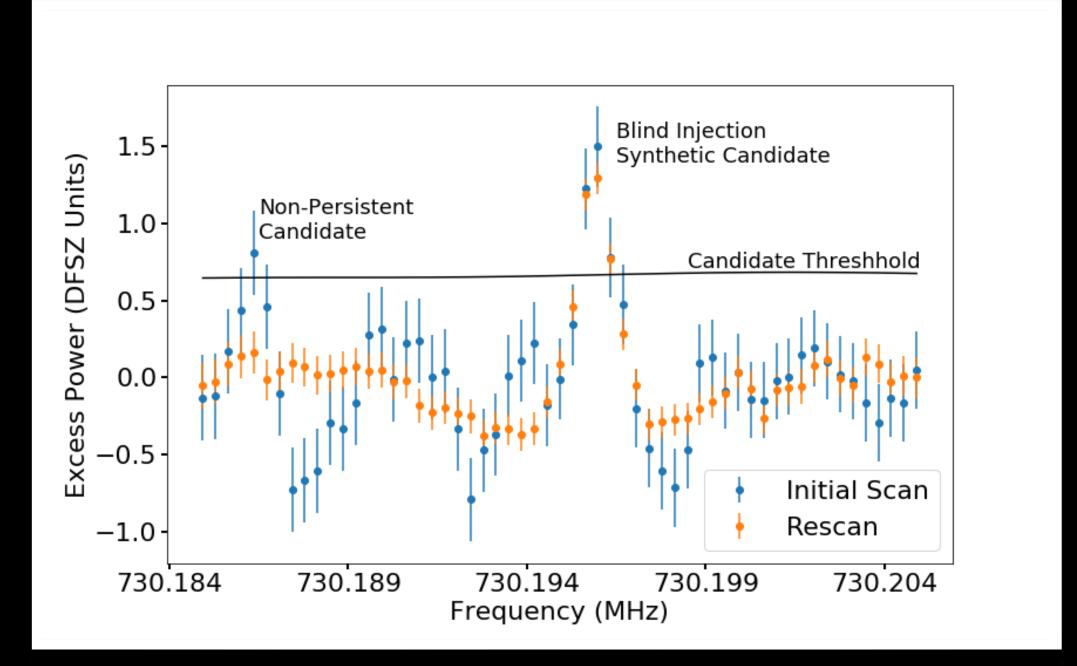
Reflection Measurements

• System noise measurements

• Synthetic injections



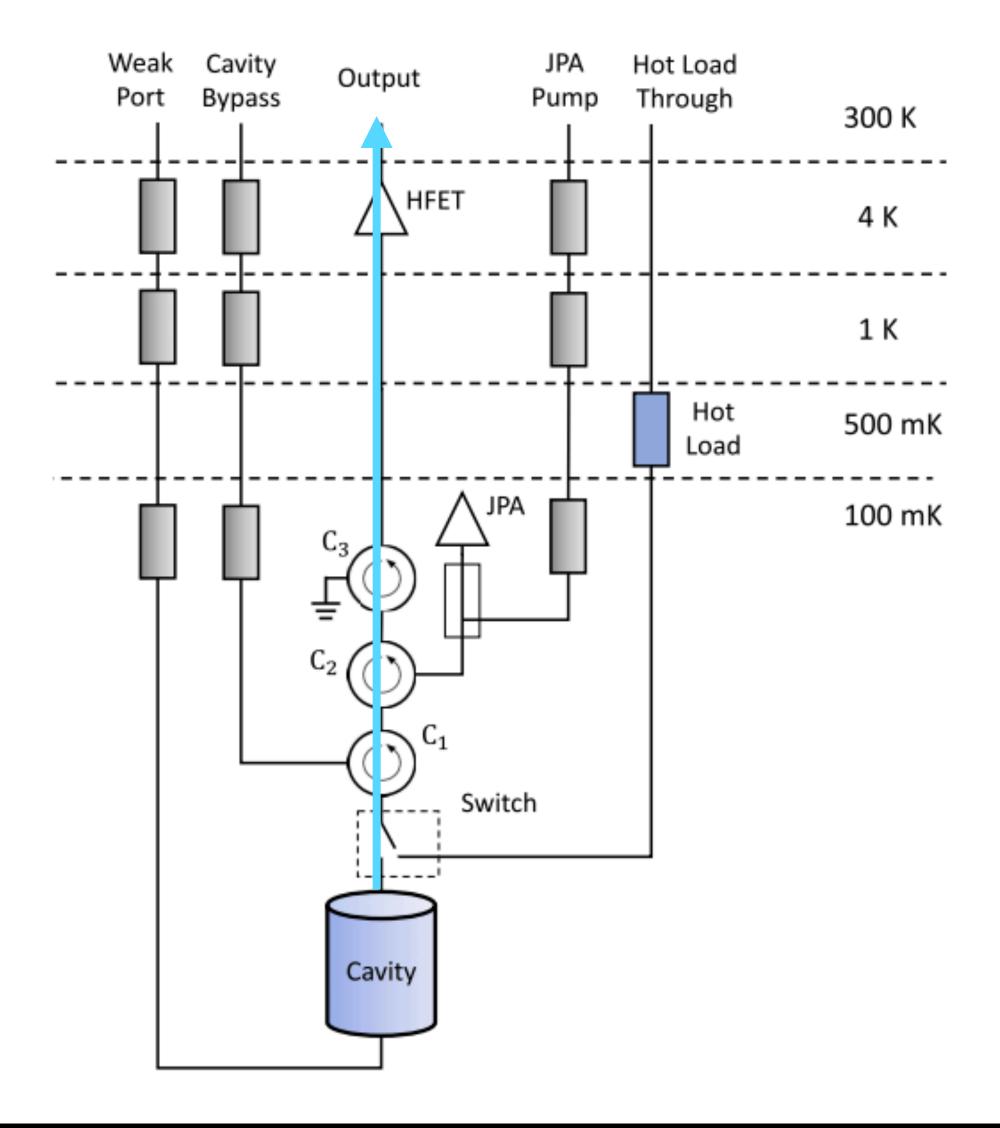
- Arb output at low frequency maxwellian-like signal
- Signal mixed up to axion frequencies
- Grad student placed appropriate attenuation
- SAG signal sent to weak port

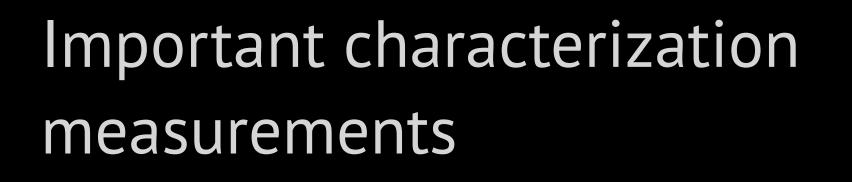


January 2018, ScientificAmerican.com 55











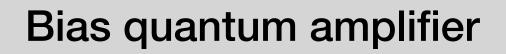
• Reflection Measurements

• System noise measurements

• Synthetic injections

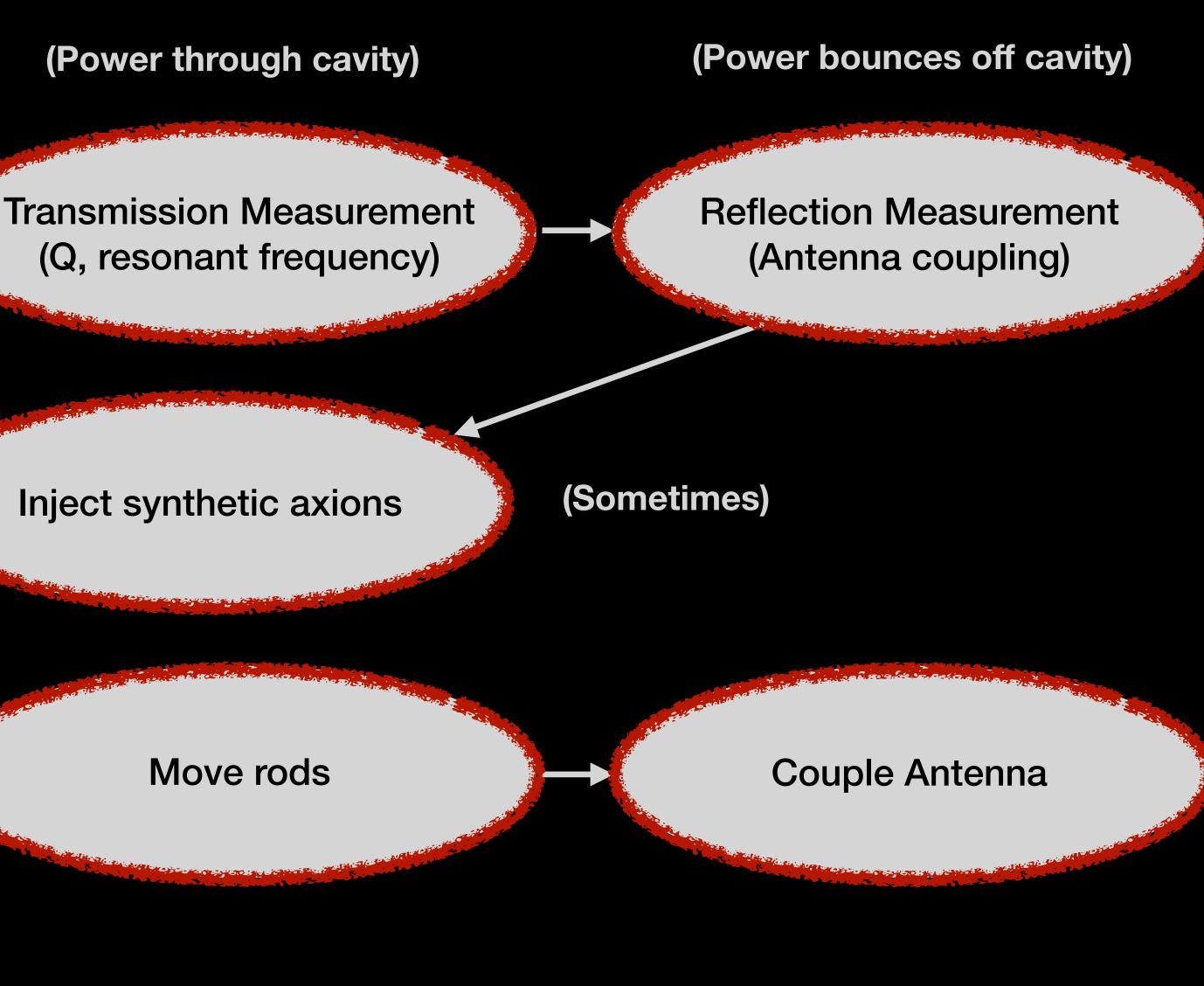


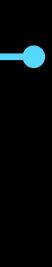
Data-taking operations



Digitize

Axion Search Data!

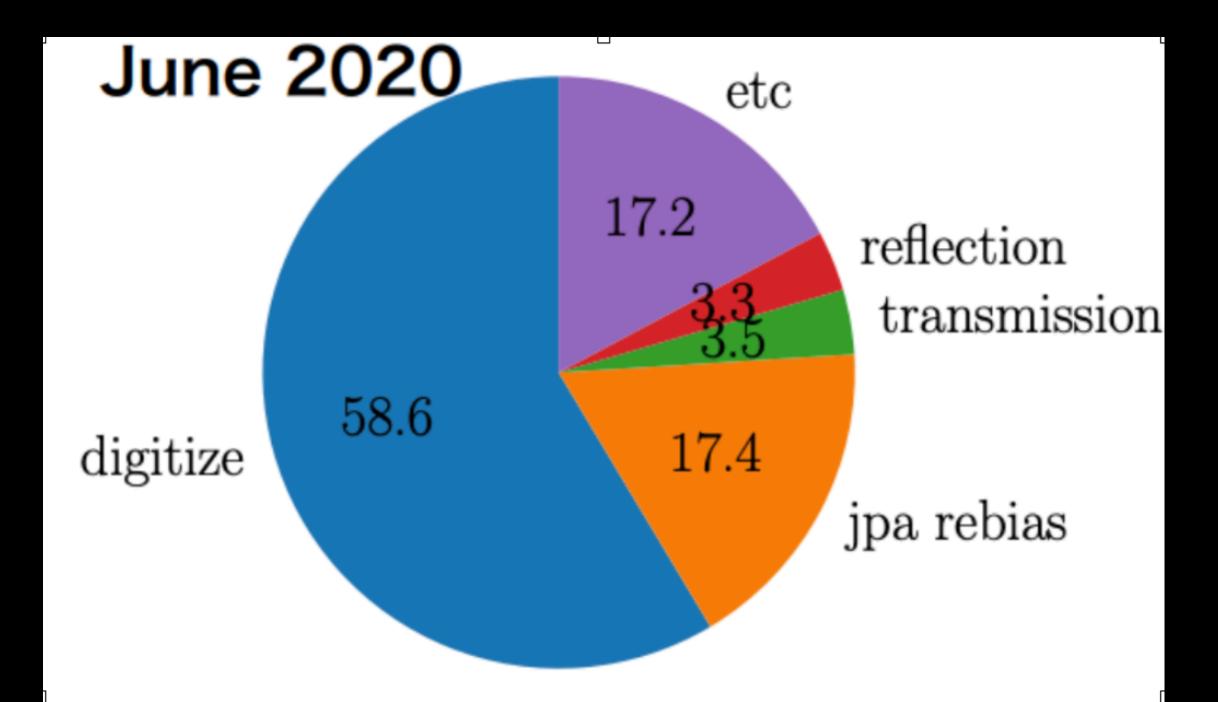


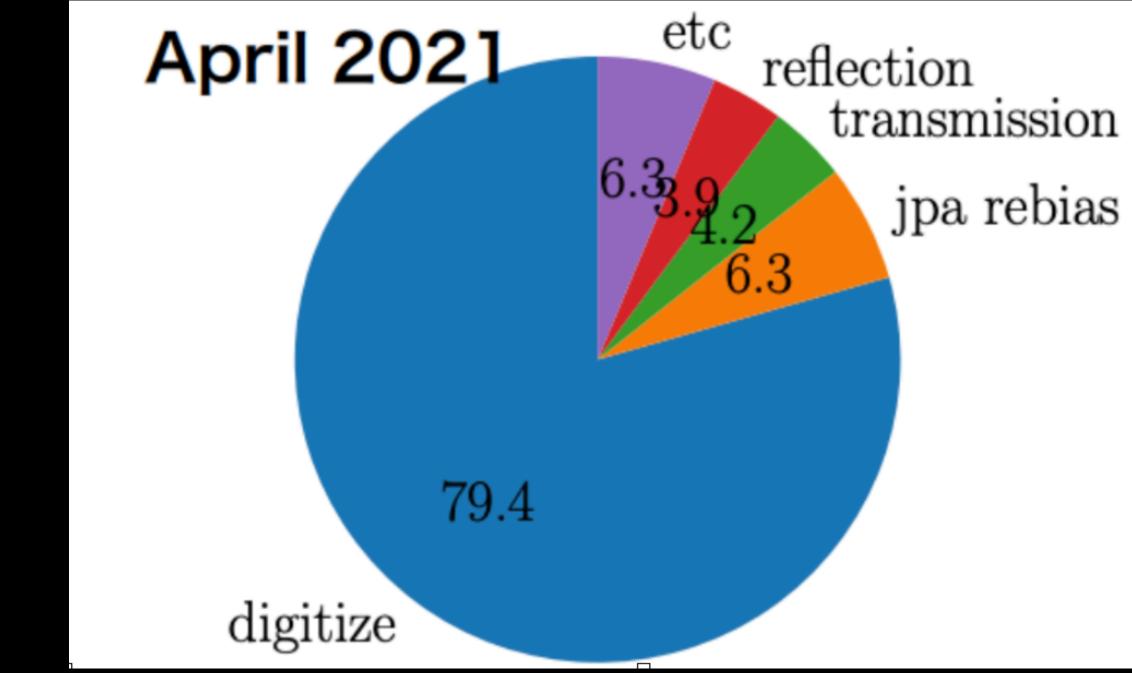


Discussion Questions

Other characterization and calibration measurements?

• At what cost?







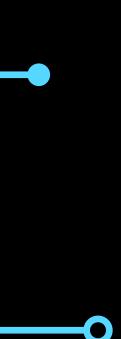
Sample Data Acquisition System

Medium Resolution

- Power spectra
 - Optimized for isothermal halo model
 - Optimized for initial detection
 - 100 Hz bin width
 - 50 kHz PSD (determined by Q)

High Resolution

- Time-series
 - Sensitive to non-virialized axions
 - Sensitive to frequency modulation from orbital and rotational motion
 - 10 mHz native bin width



"Standard" Axion Signal

Power

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Frequency

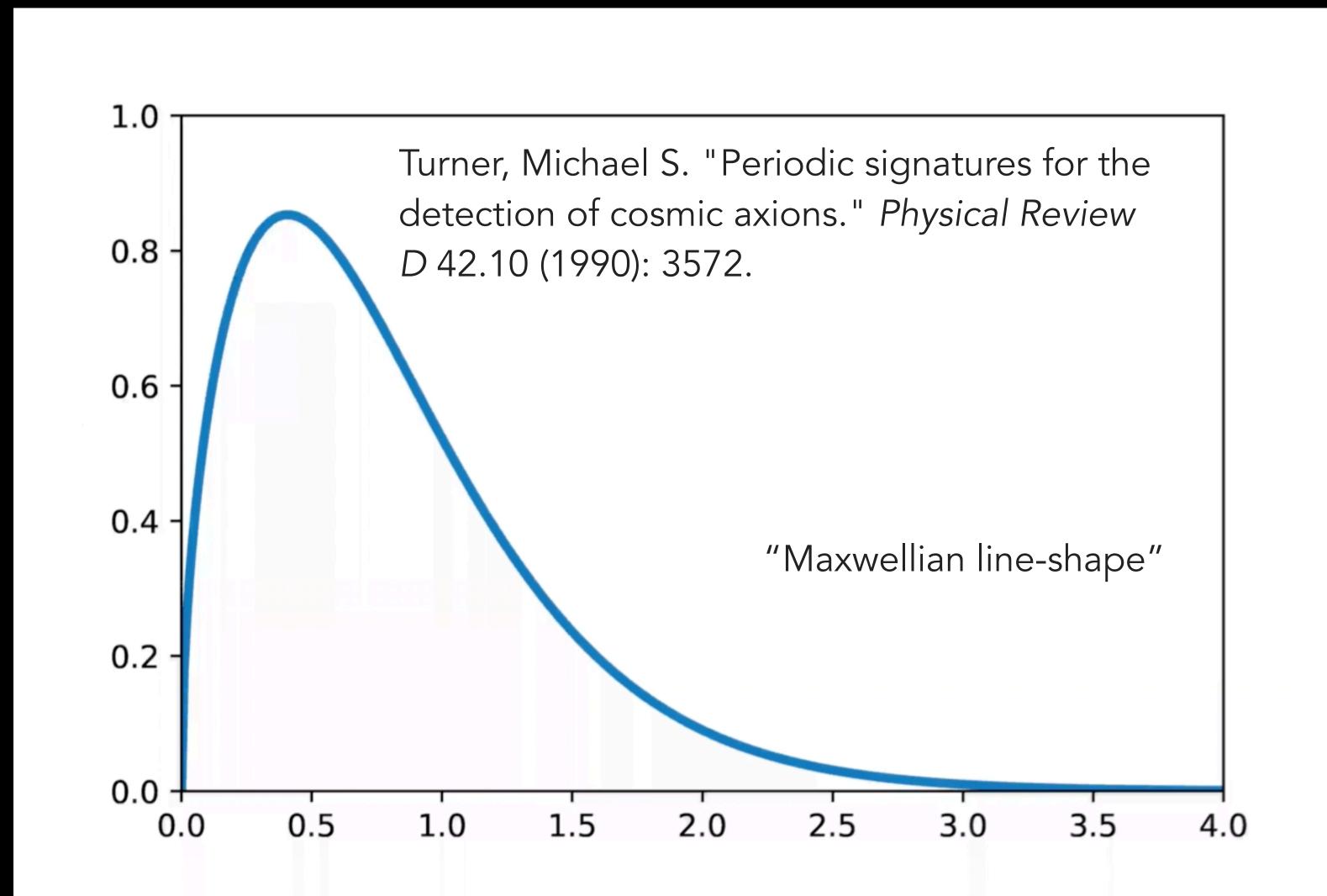
"Narrowband" peak with a signal strength of ~10⁻²³ watts

 $P_{a \to \gamma} \propto B^2 V C g_{\gamma}^2 \rho^2 f Q$

- B = magnetic field
- V = volume
- C = form factor
- g_{γ} = model-dependent term
- ρ = dark matter density
- F = frequency
- Q = quality factor



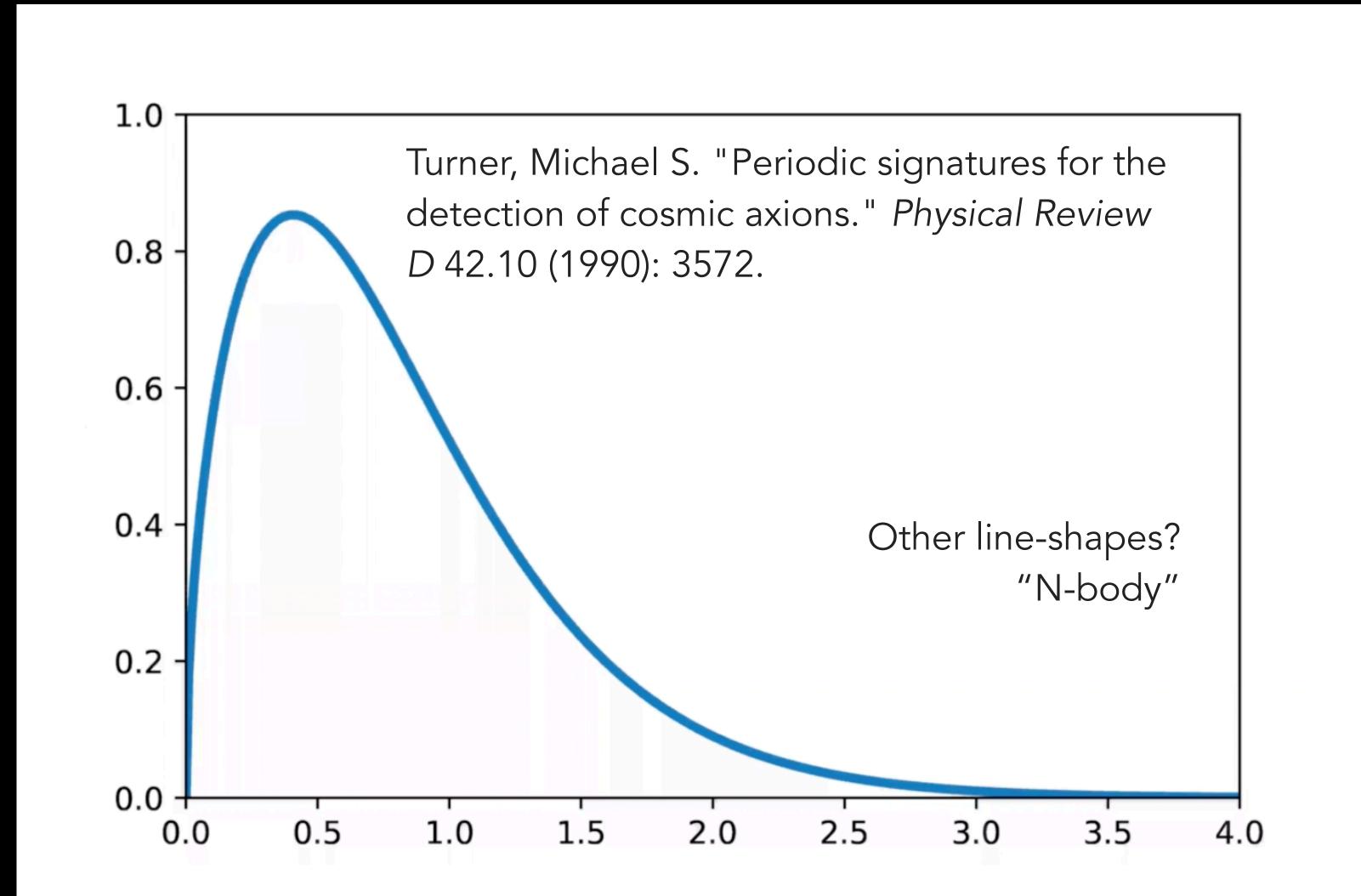
Axion Doppler Shift



Probability

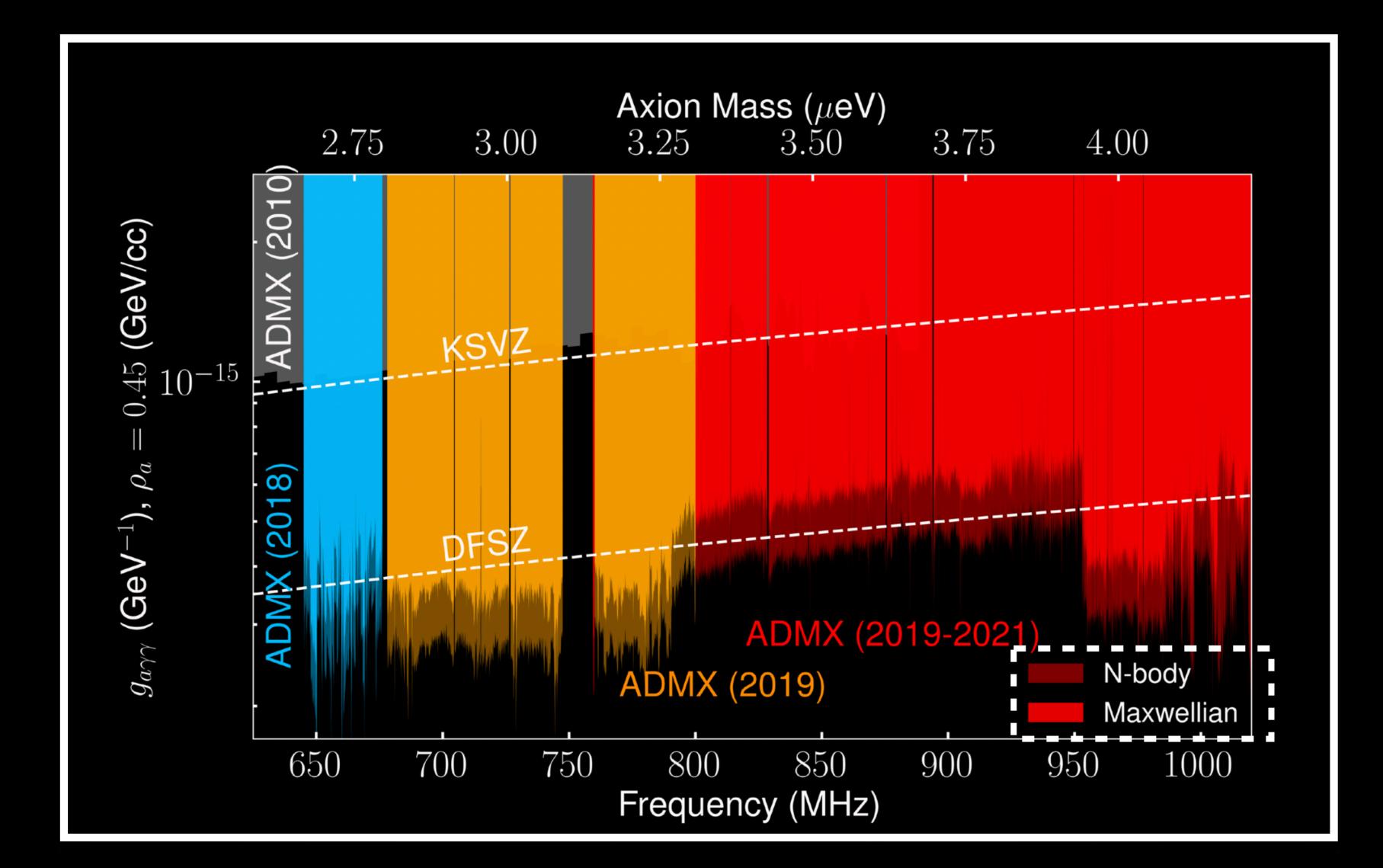


Axion Doppler Shift



Probability







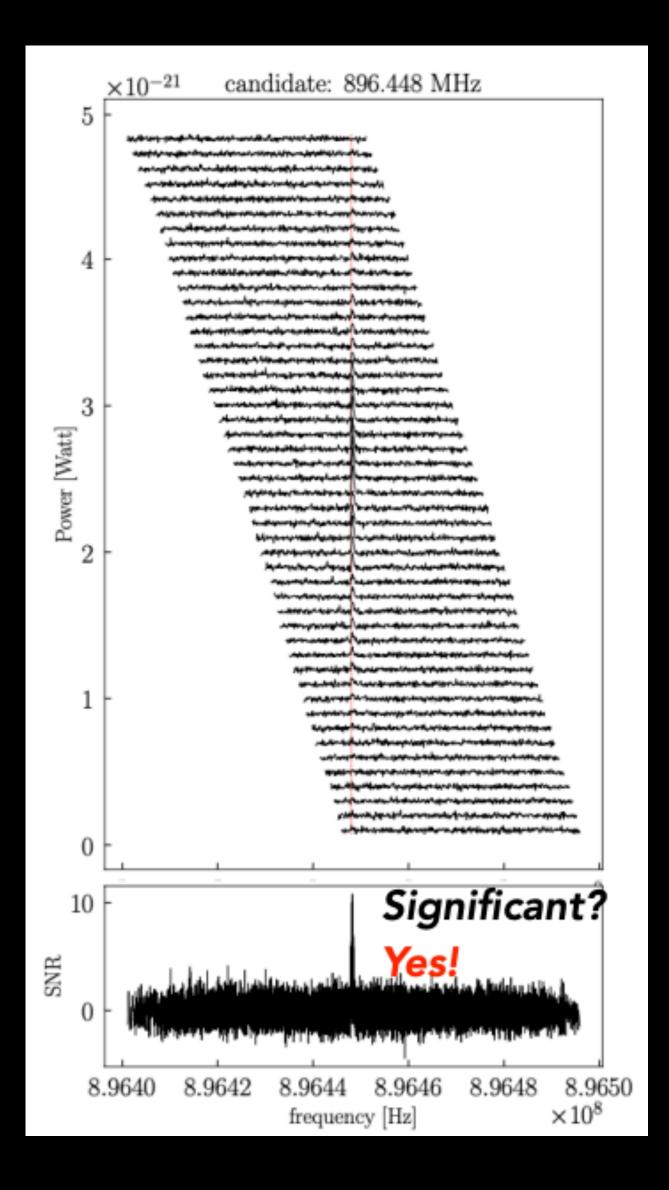
Discussion Questions

- Alternative data formats?
 - Broadband search data?
 - Different bin widths?
 - Alternative line-shapes?
 - Value of time-series data

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Is it really an axion?

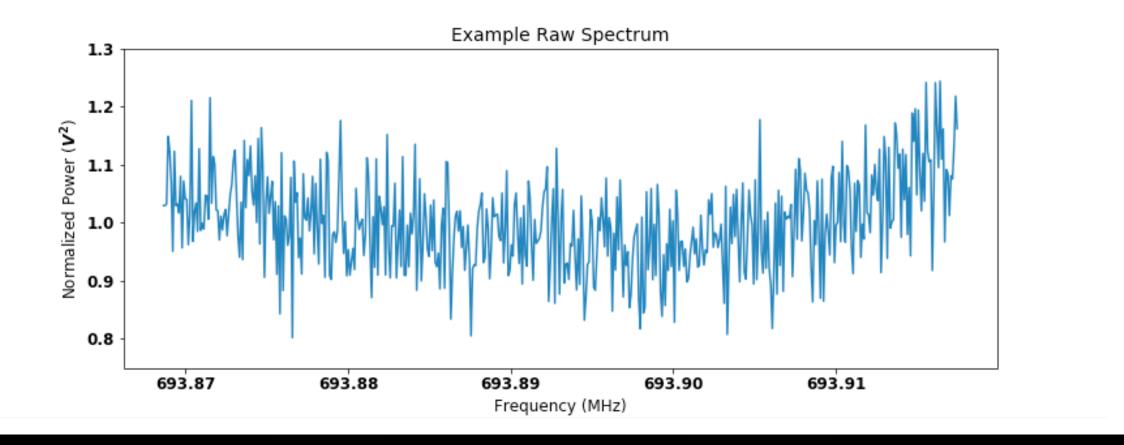


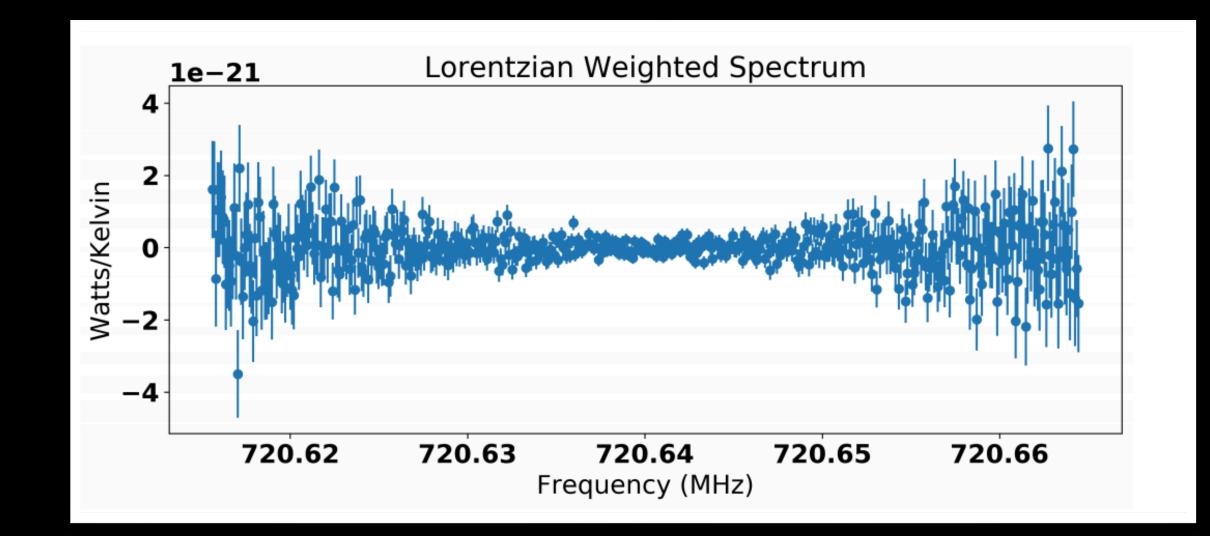
- Must not be a hardware synthetic signal
- Must not be ambient radio frequency interference (RFI) detectable with room temp receiver
- Must appear in every spectrum at that frequency (persistent).
- Must be enhanced on-resonance.
- Must be suppressed in modes that do not couple with the axion.
- Signal power scales as B².

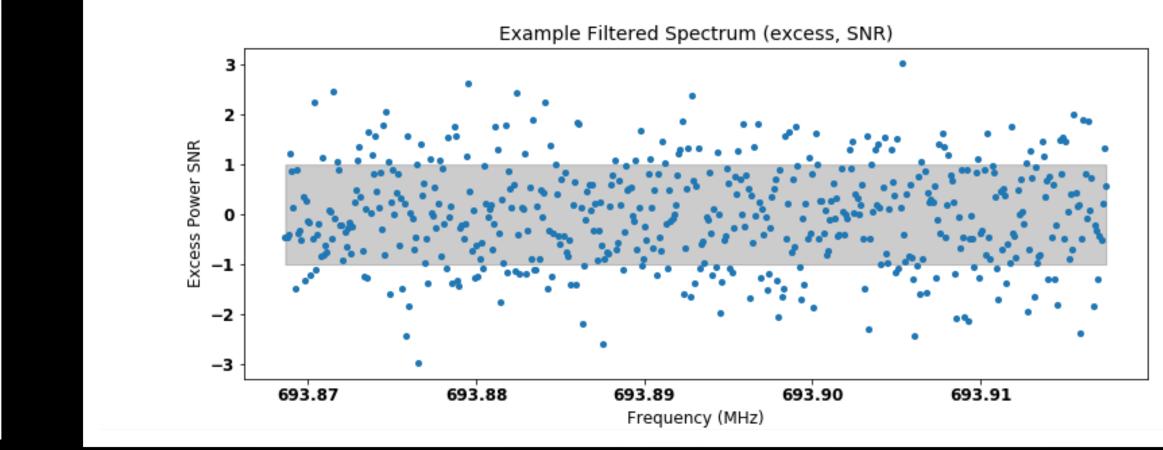
the detector

ADMX hardware synthetic injection mimics an axion signal in

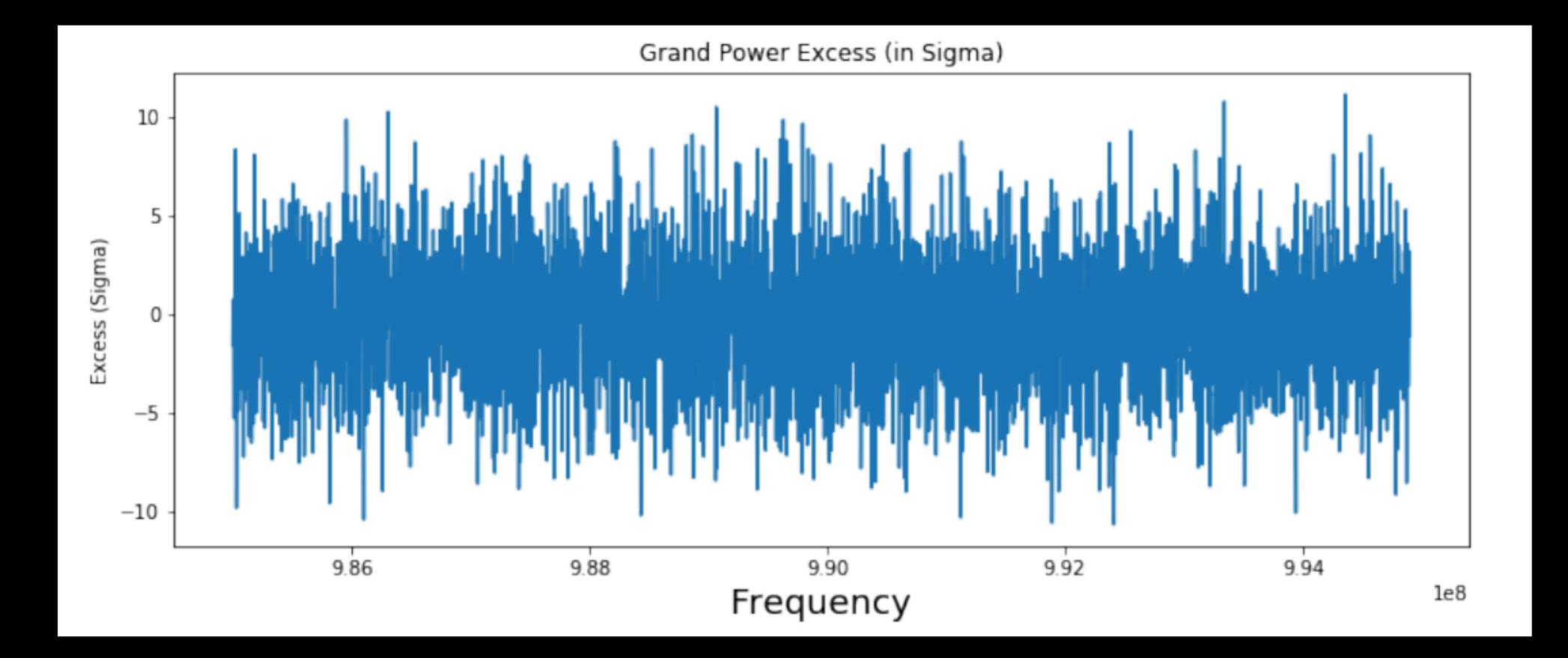






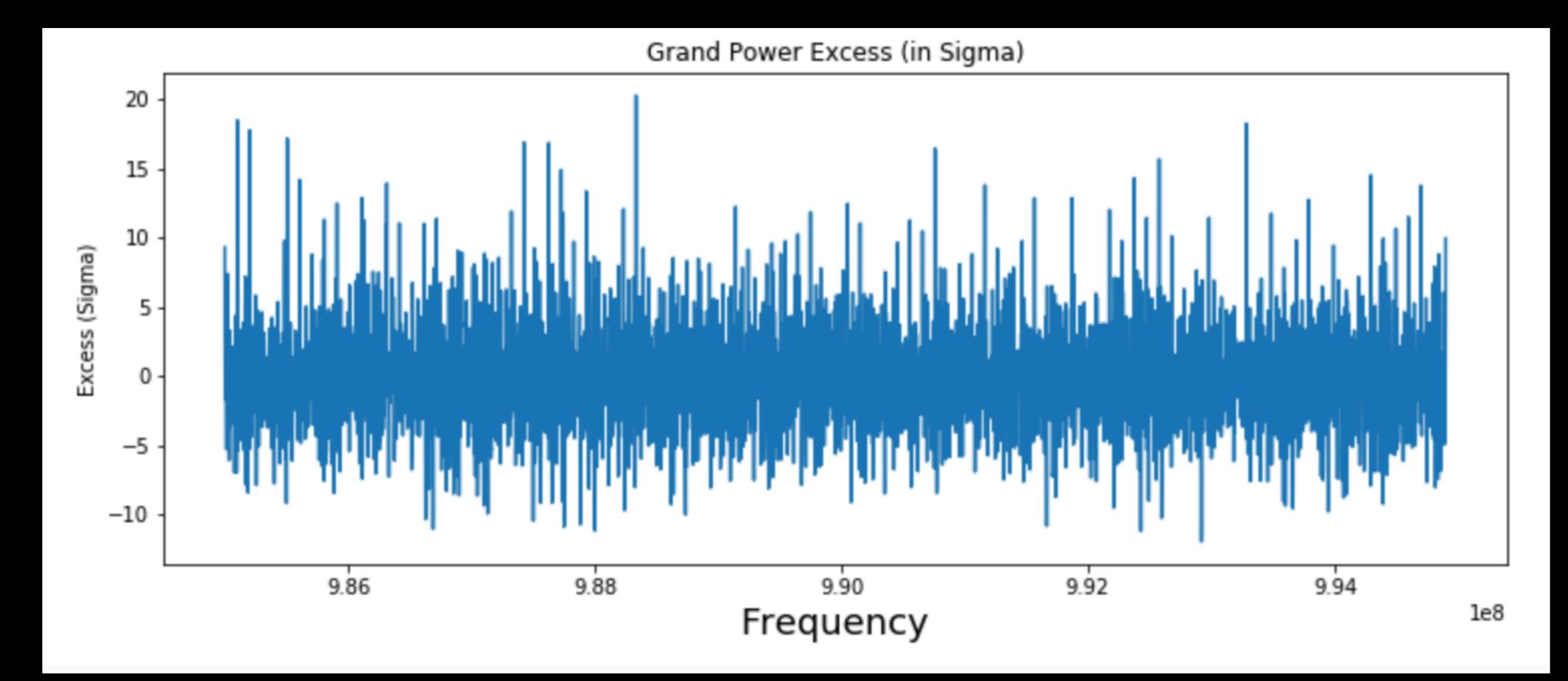






Example Grand Power Spectrum





Software synthetic injections



When do you decide to rescan? 3 conditions:

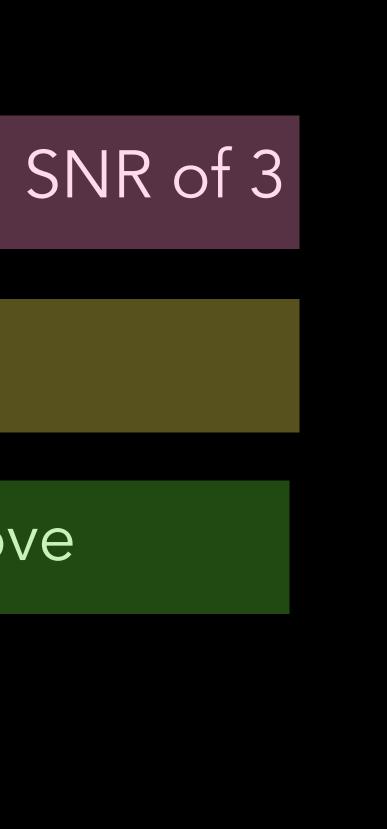


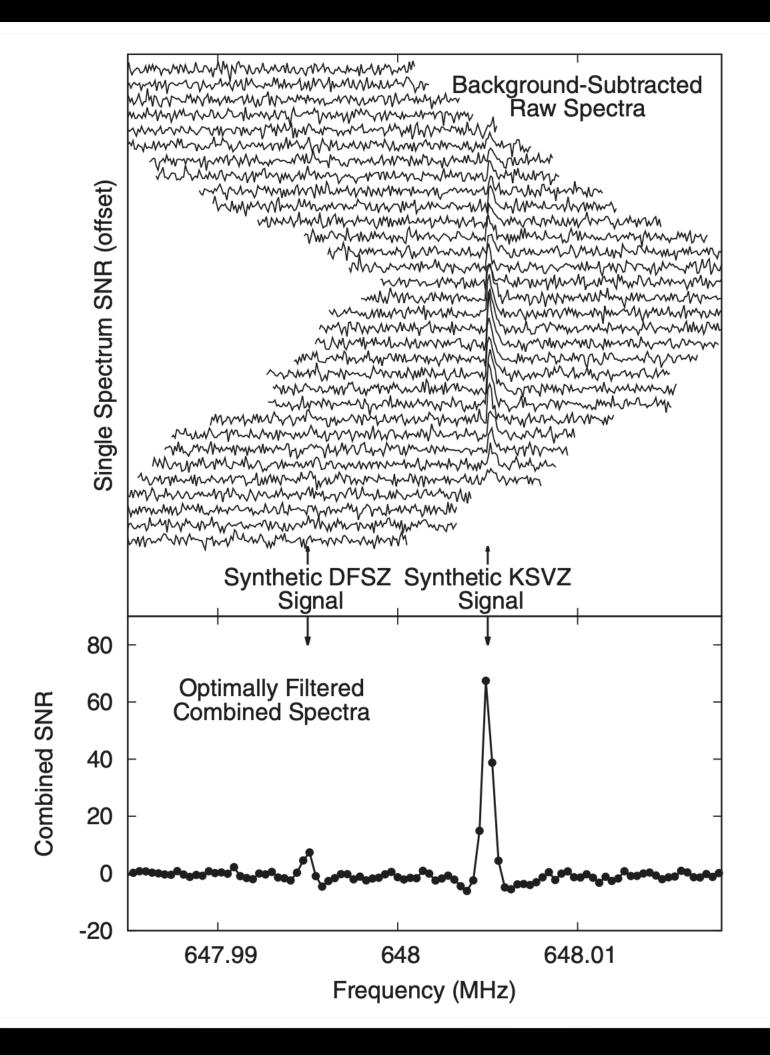
• 3.4σ excess

• Excess at DFSZ threshold or above

 $P_{\text{measured}} + 0.85\sigma > P_{\text{DFSZ}}$

There will always be some of these remaining just due to statistics!







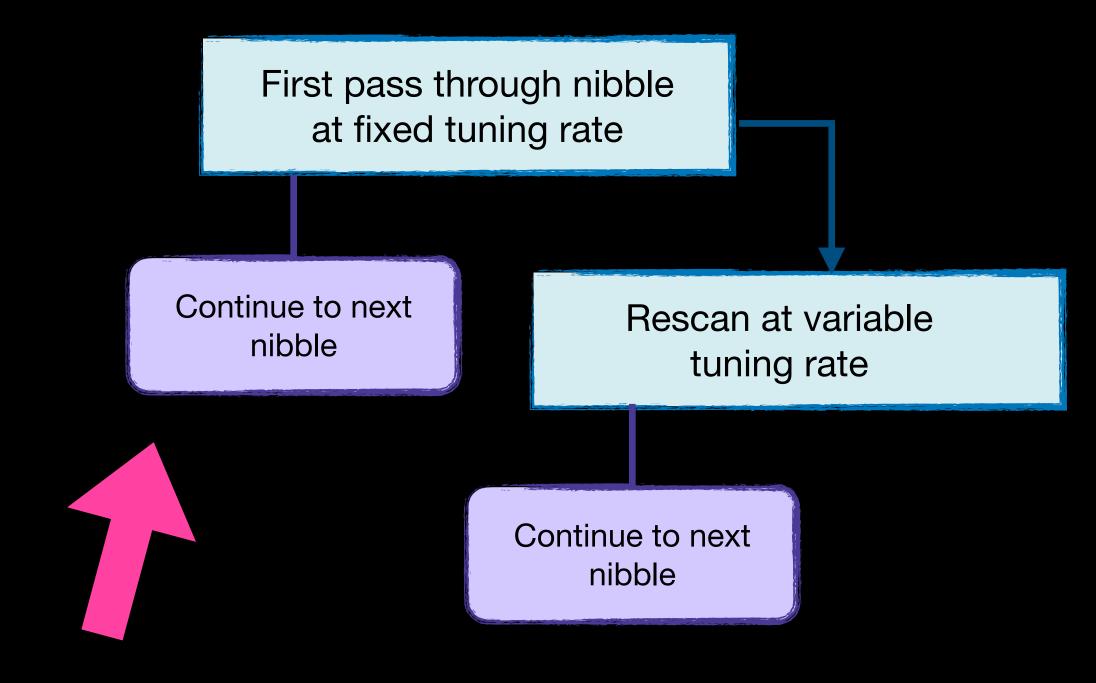
First pass through nibble at fixed tuning rate

Continue to next nibble



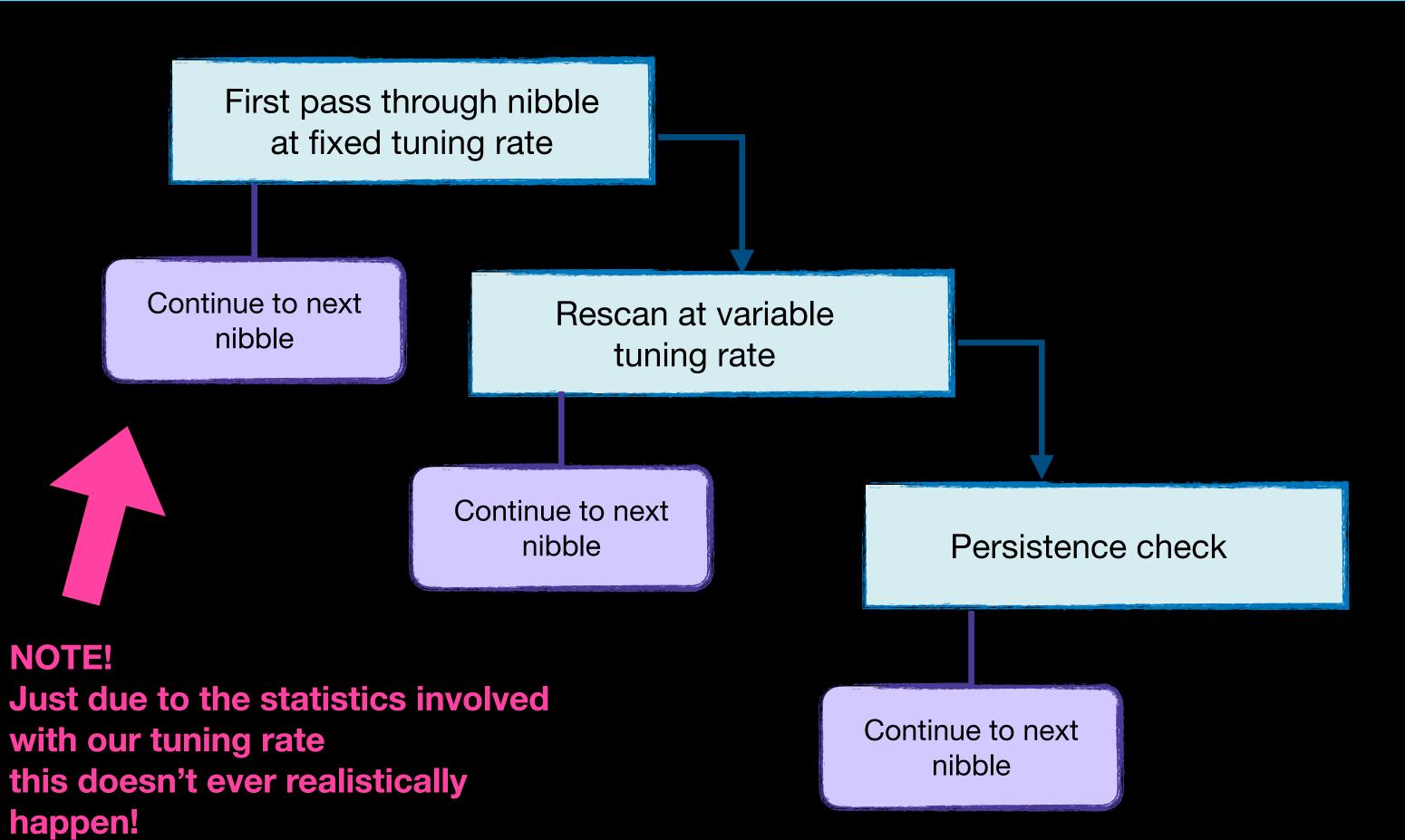
NOTE! Just due to the statistics involved with our tuning rate this doesn't ever realistically happen!





NOTE! Just due to the statistics involved with our tuning rate this doesn't ever realistically happen!

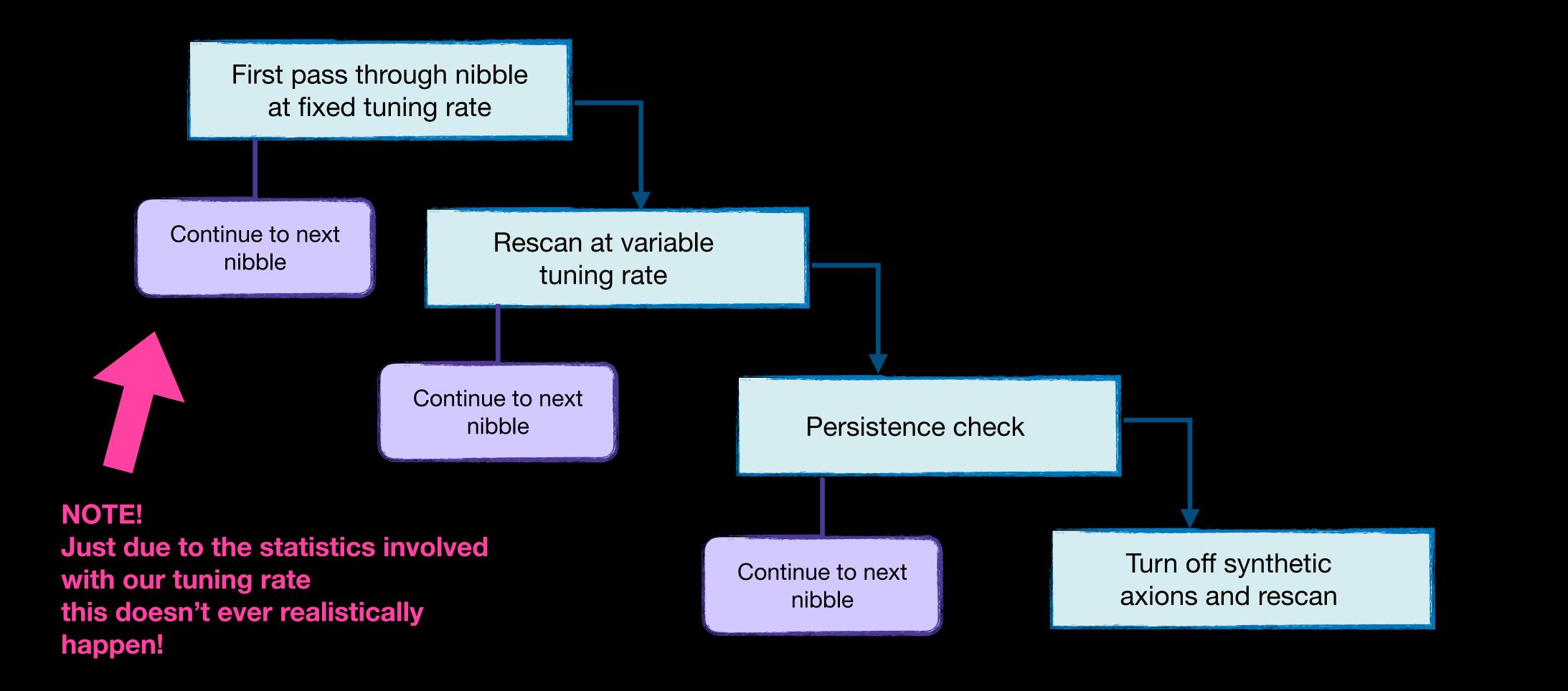




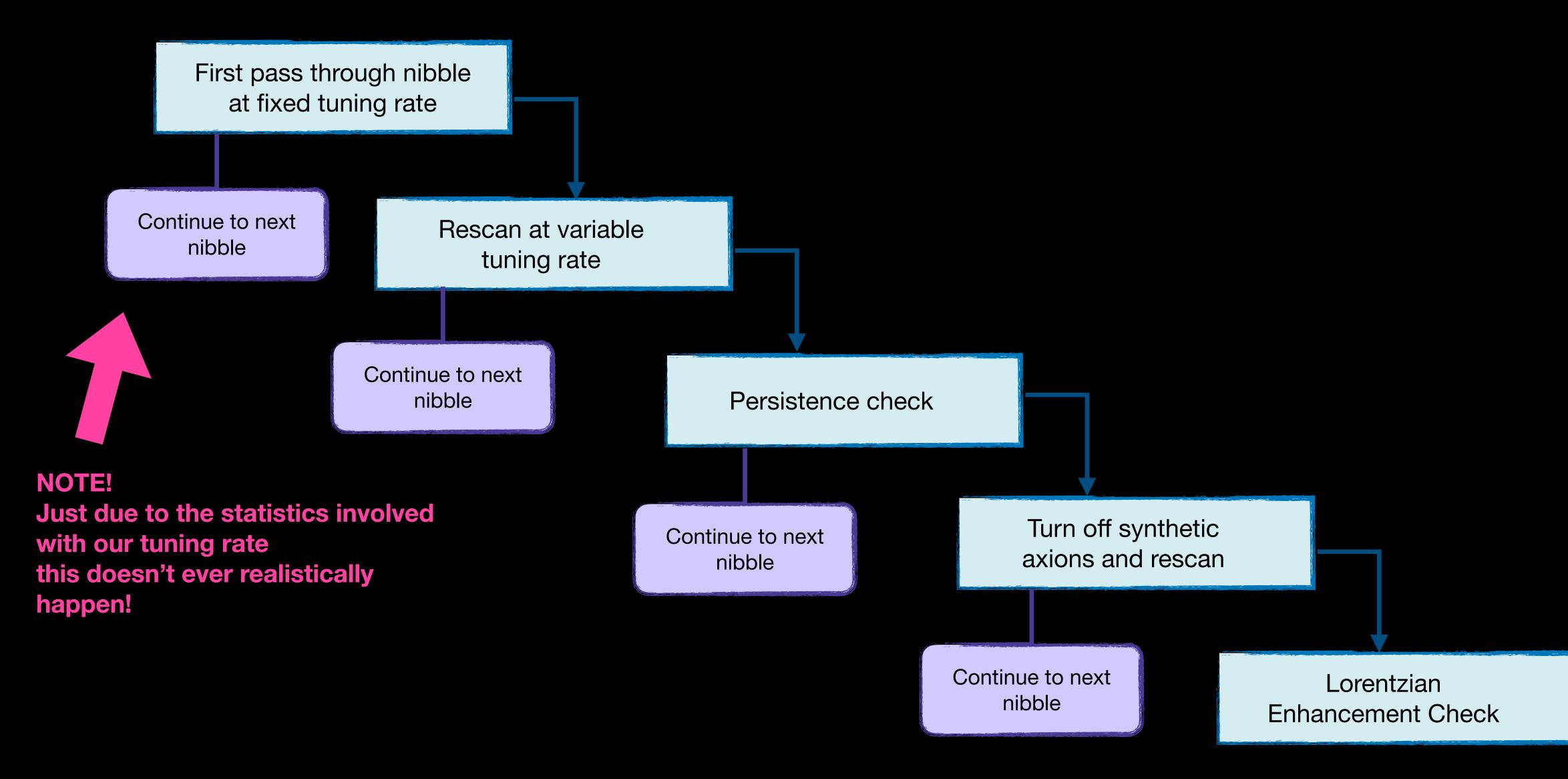
candidate: 896.448 MHz $\times 10^{-21}$

5State of the local division of the local div والمرجل ومرجل والمرجات والمراجع والمراجع والمراجع والمرجع والم **** بالمحطولة البأسي المالية مردسة بمعترية والمرعد معادية المراجع والمردوي 4 and the state of the second <u>مەرەبەر مەرەبەر ئەرەرىمەرىمەرەر مەرەبەر مەرەبەر مەرەبەر مەرەبەر مەرەبەر مەرەبەر مەرەبەر مەرەبەر مەرەبەر مەرەبە</u> white water his short water the second And the second s A A MARY AND A MARY AND A 3 ------[Watt] A TRACE AND A DESCRIPTION OF TAXABLE man and the state of the state and a second - Incorporation ----Power NAMES AND ADDRESS OF TAXABLE PARTY ------بمادر مادر وال 9 Marrie and and an and an international states anonaria and the second sec Norman Adapter and dealers and the second THE ROOM IN THE OWNER OF THE OWNER OWNE Lander Merifenter verherbeiten an der Meinen son der ------**** and the second s , internet for a first second starting the second starting of the se Significant? 10SNR 0 An all the second states and second states in the 8.96408.96428.96448.96468.96488.9650 $\times 10^8$ frequency [Hz]

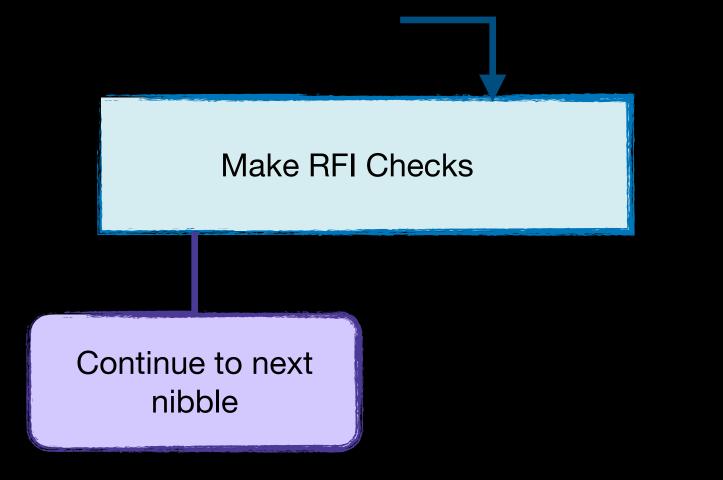




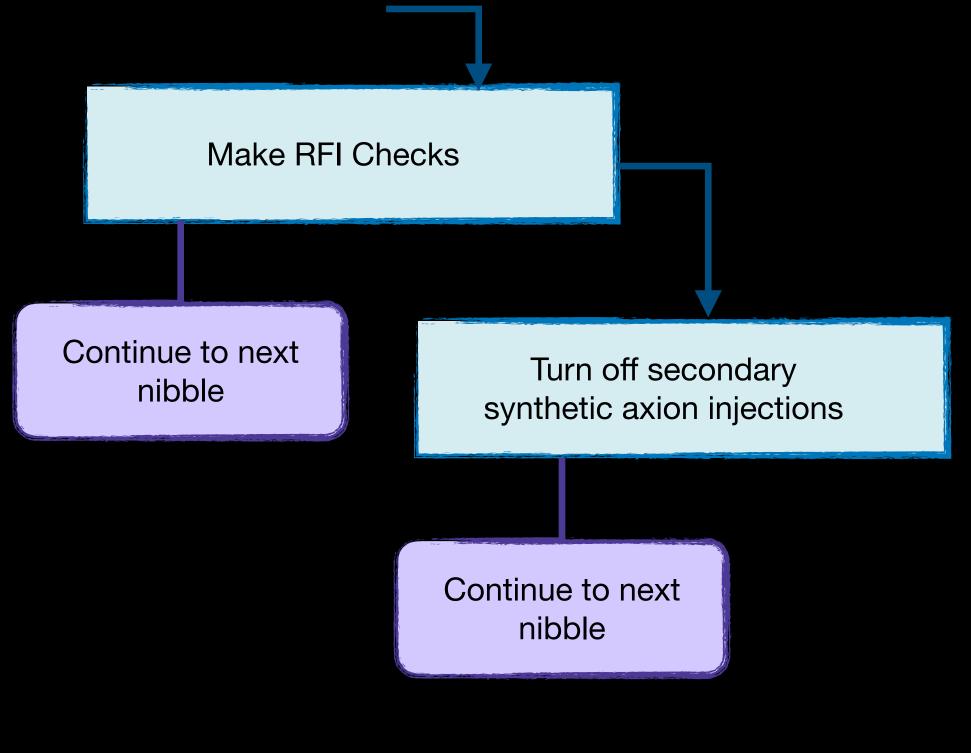




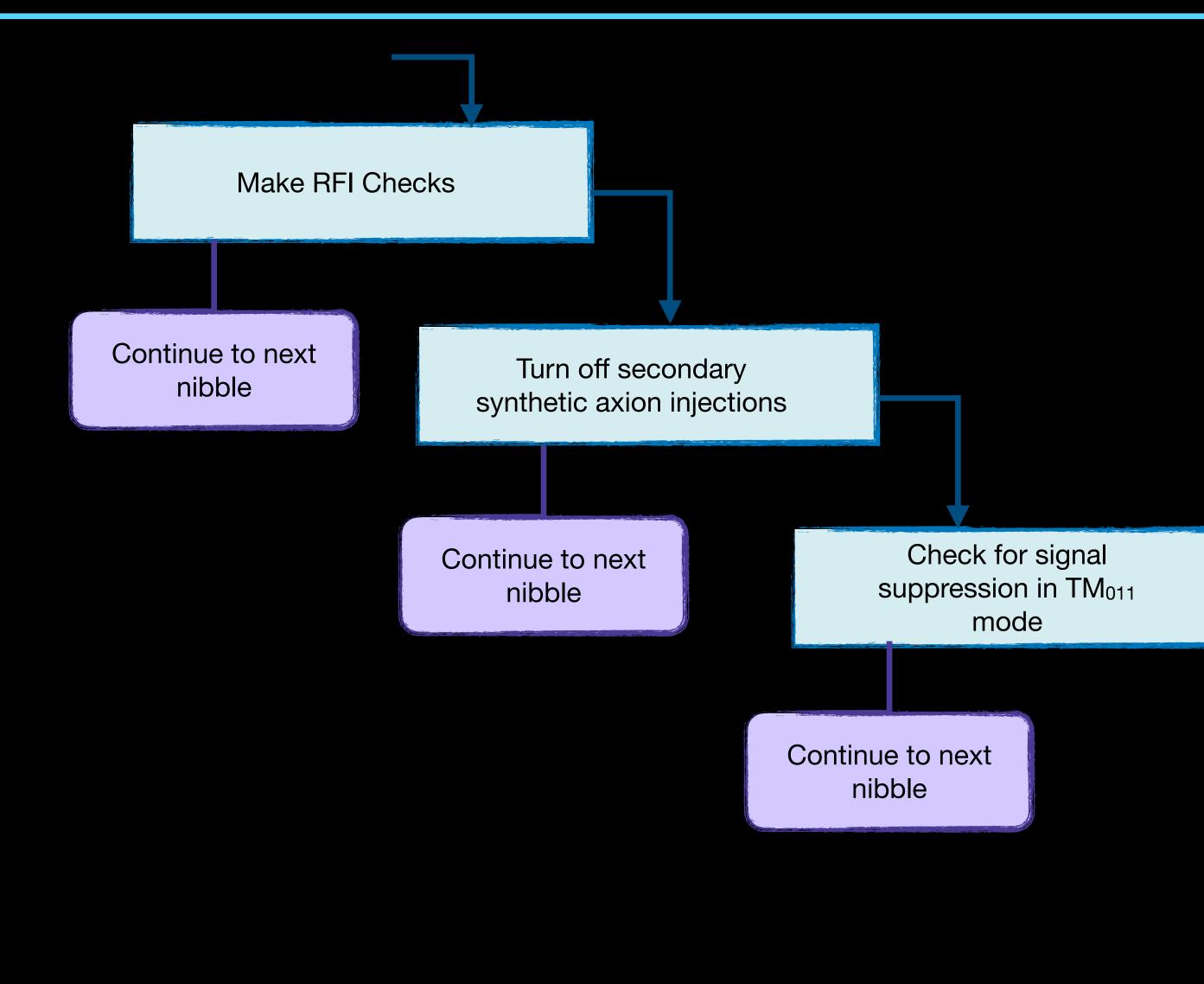




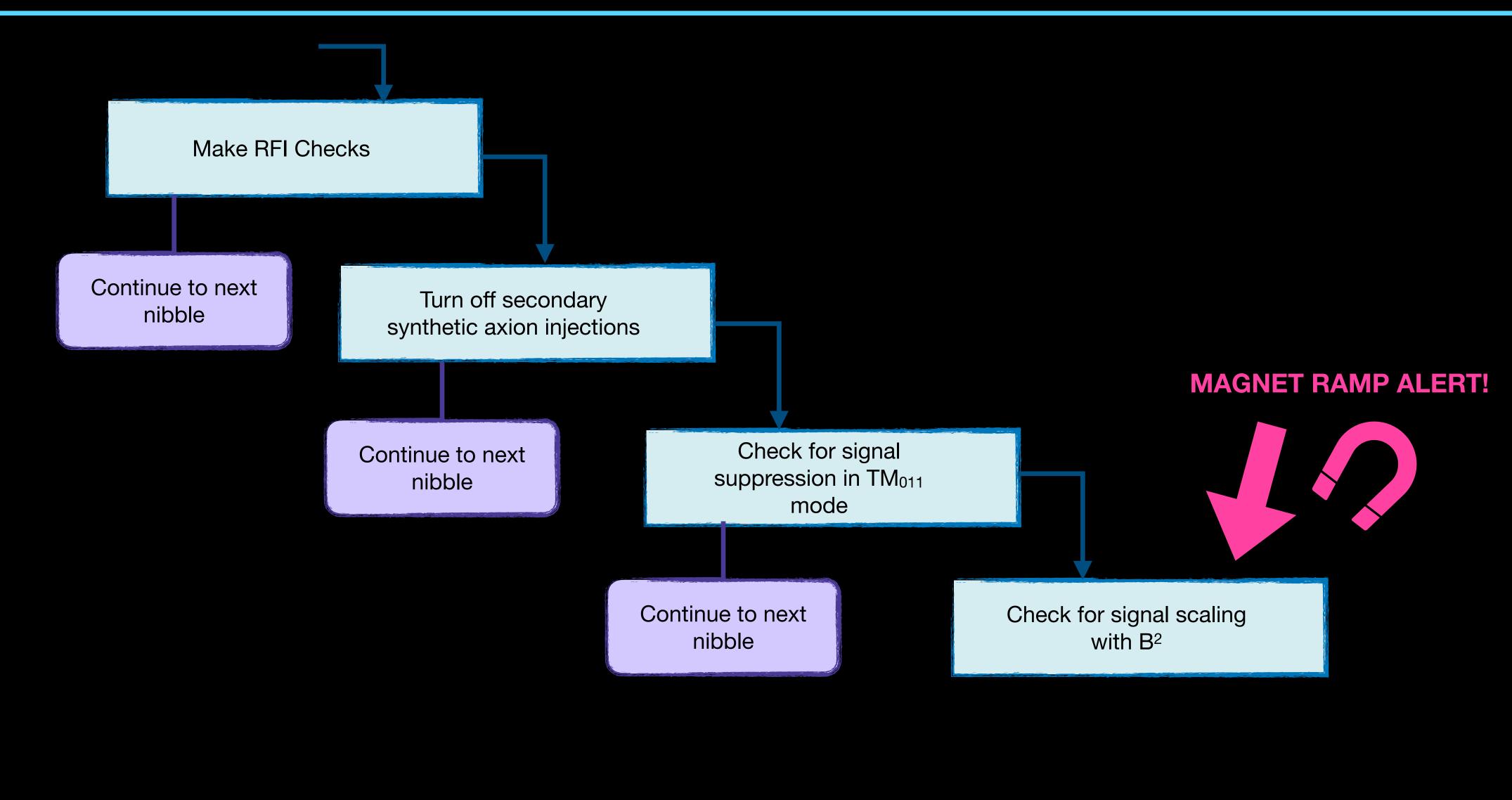




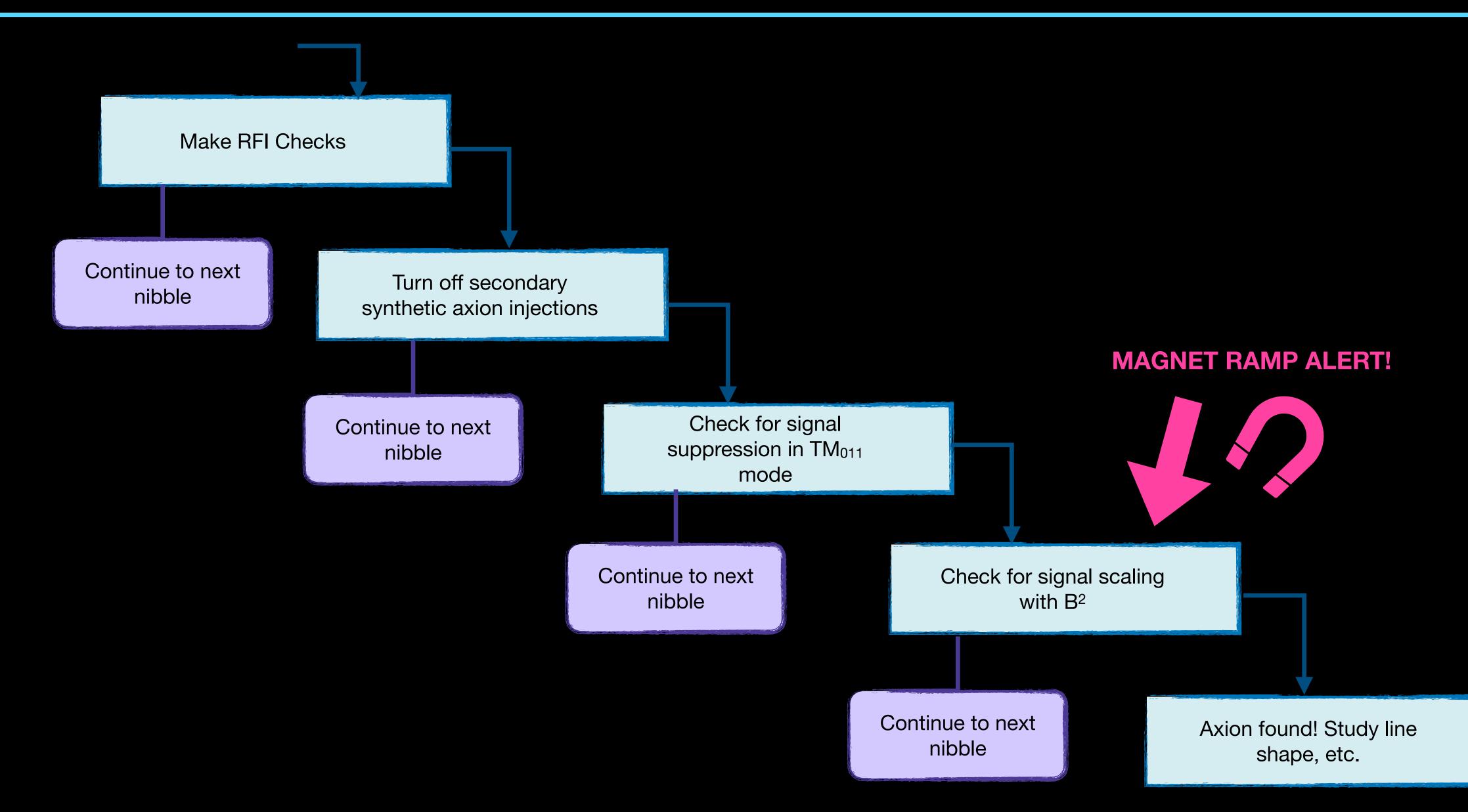












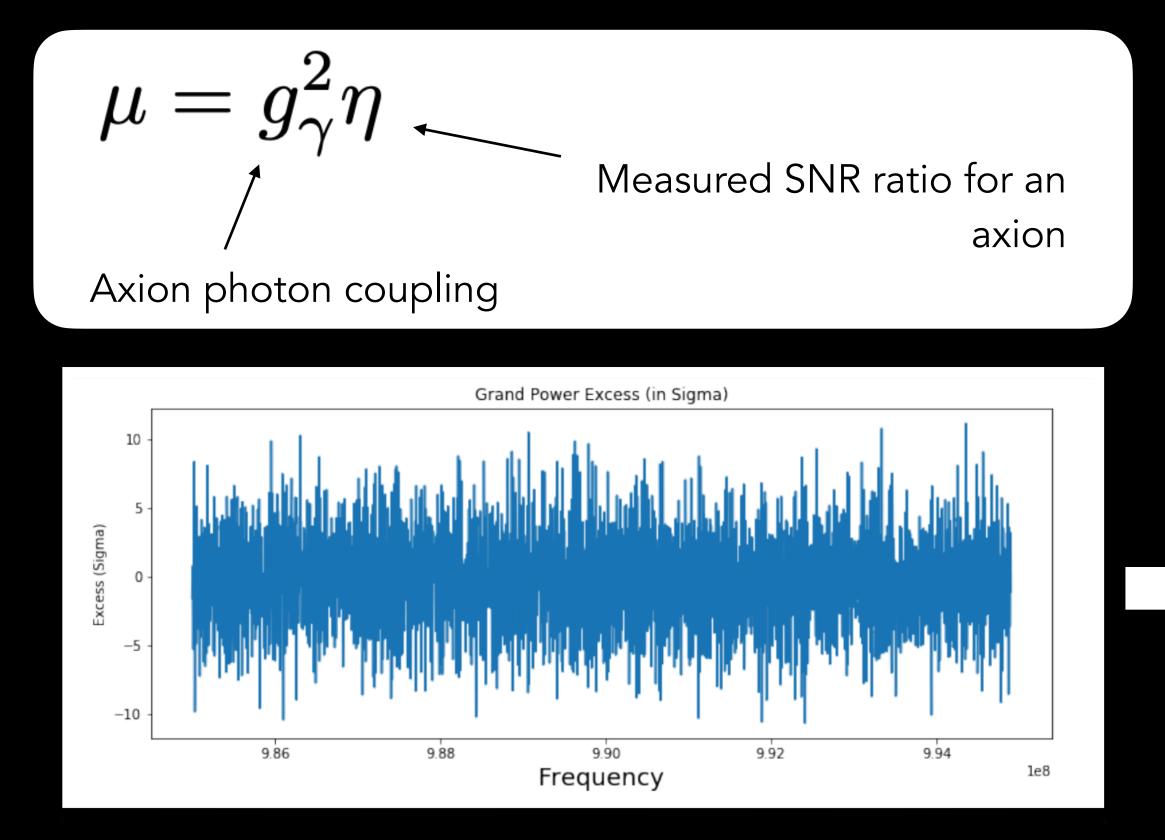


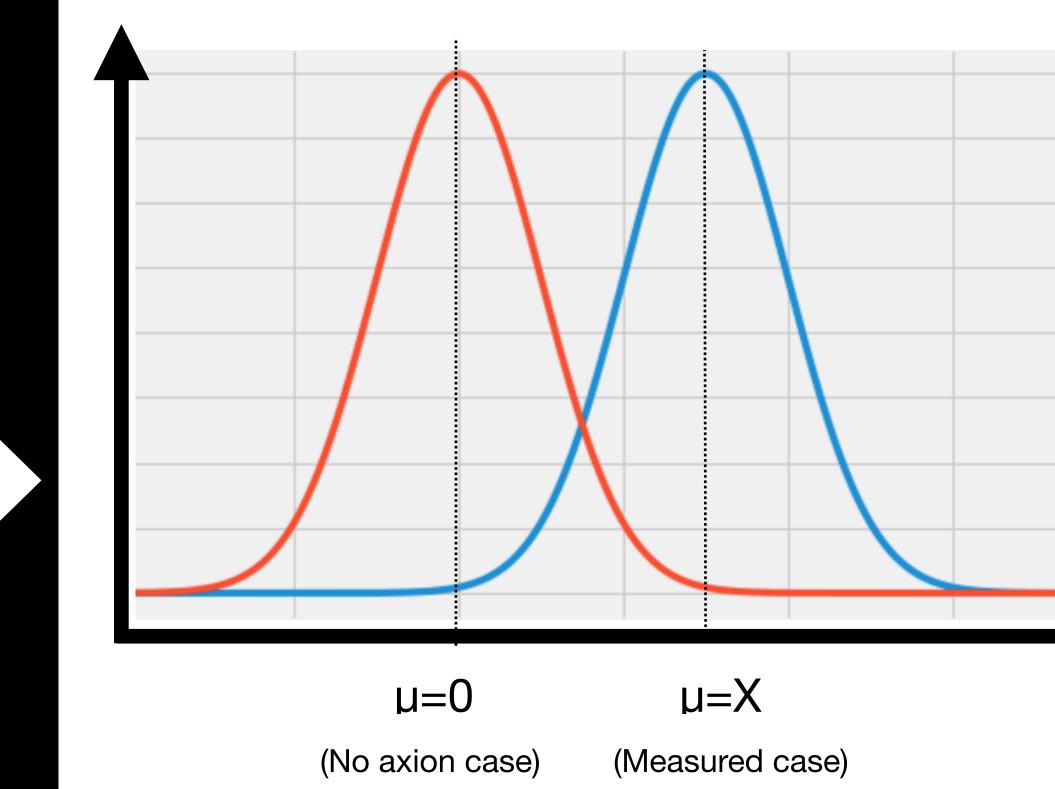
Discussion Questions

- Does this decision tree preclude interesting models?
 - Improved communication between experiments
 - Improved communication to theorists

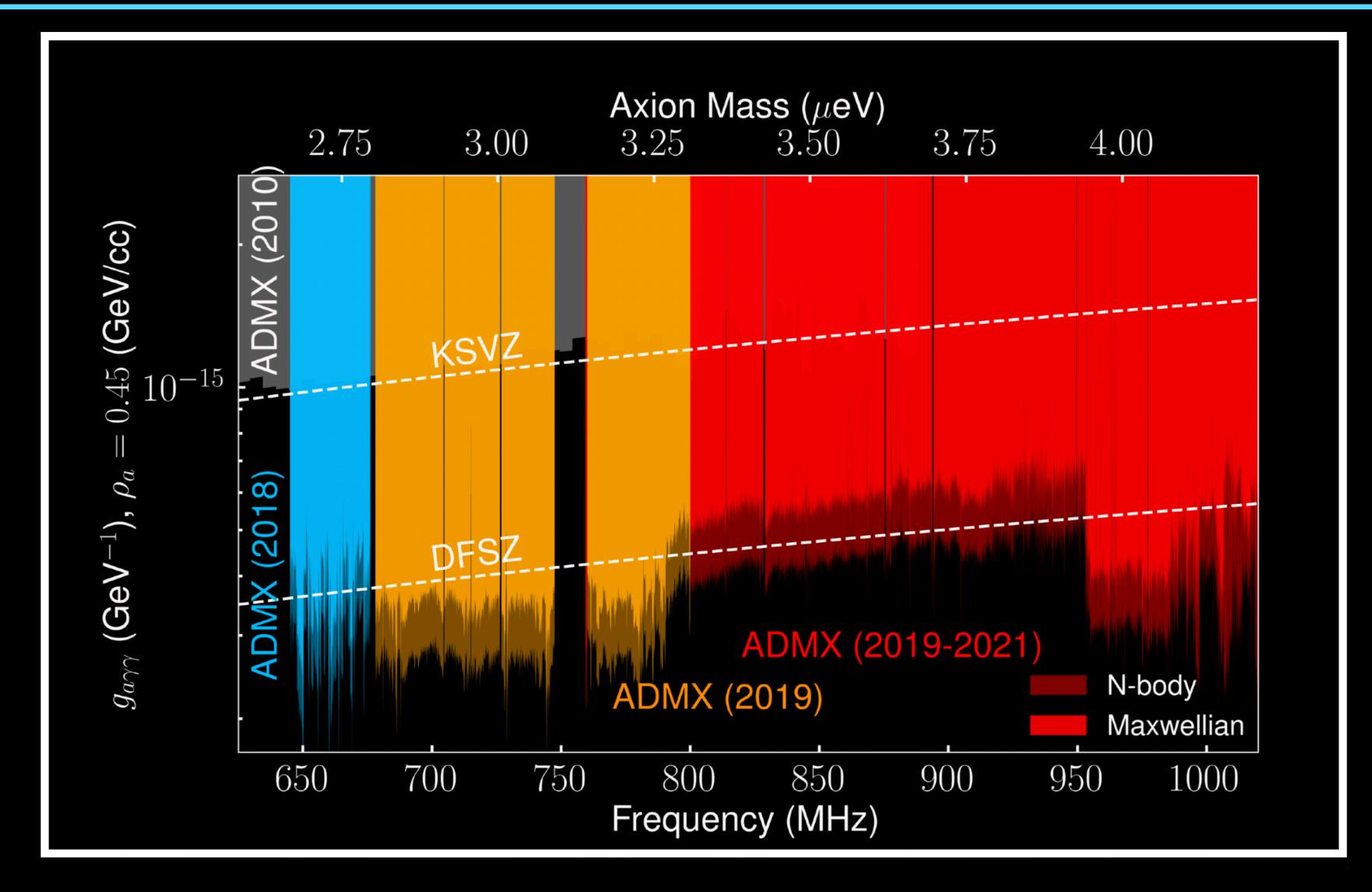


ADMX Exclusion Limit

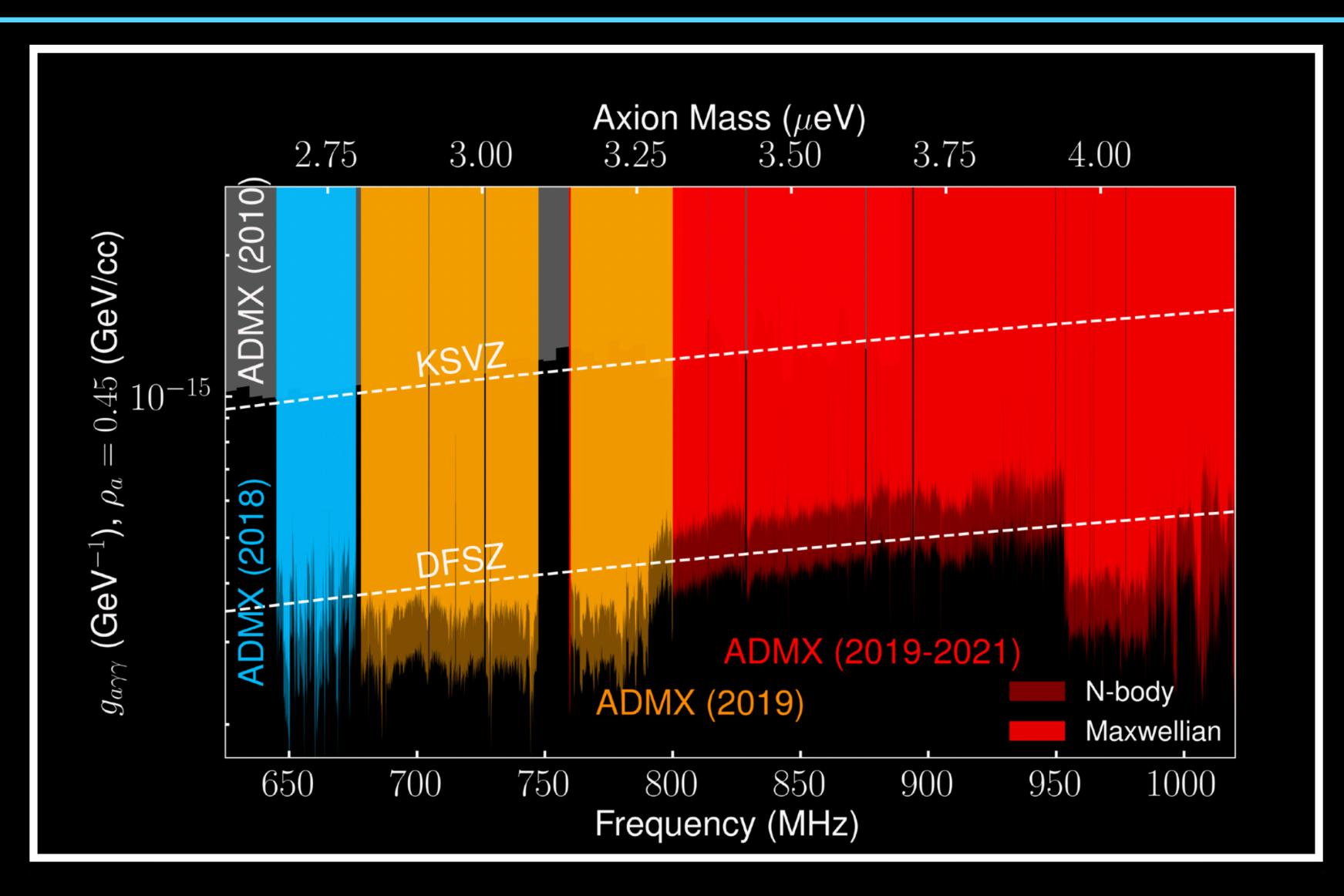






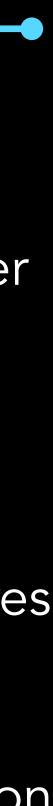


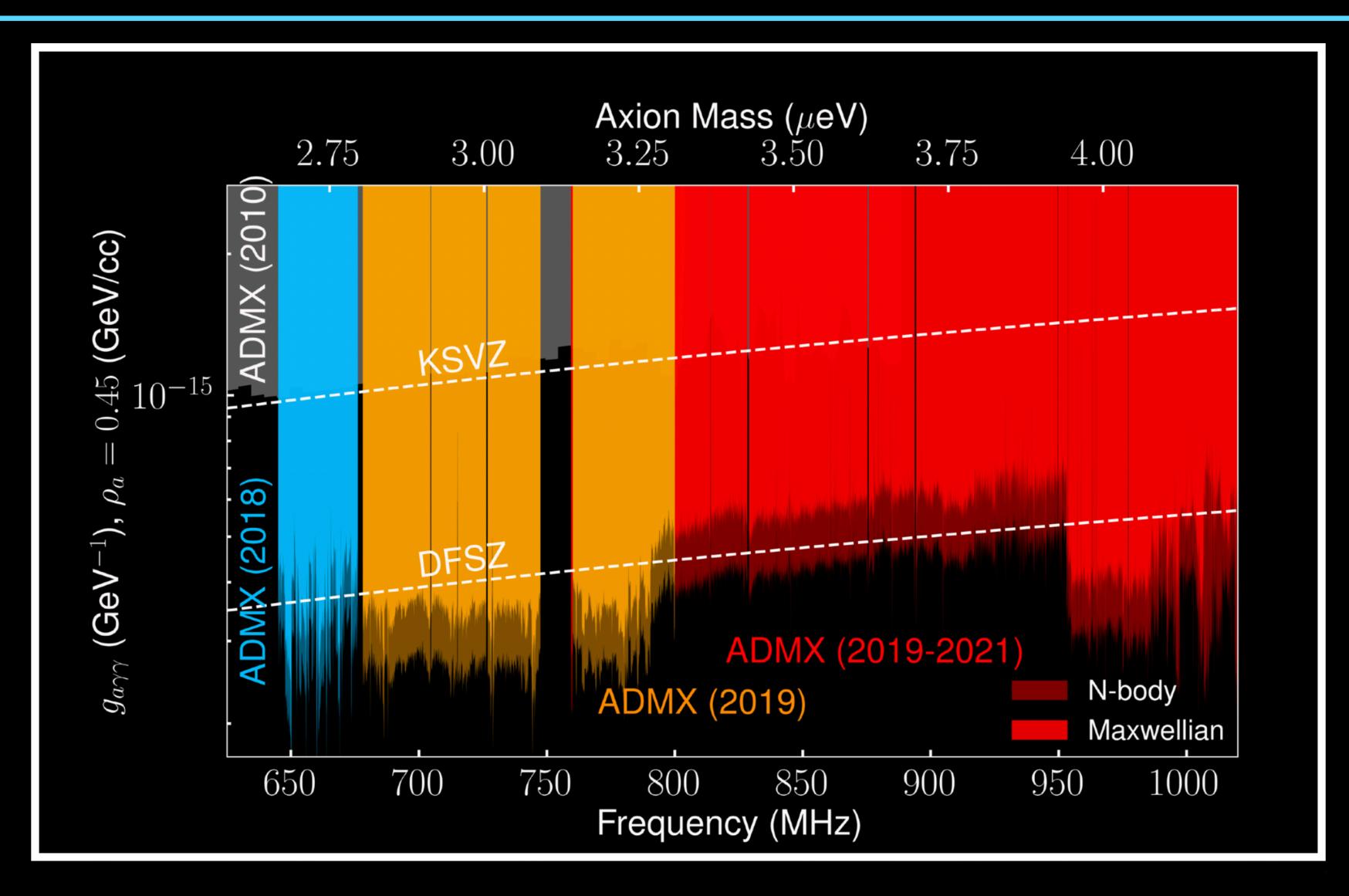




Assumptions

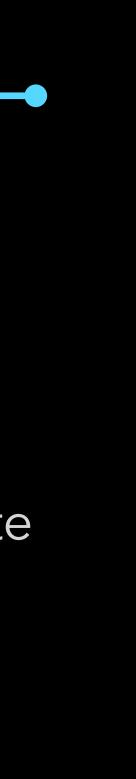
- 0.45 GeV/cc dark matter density
- Isothermal halo model
- Does not resolve features
 < 300 Hz
- Frequentist interpretation





Unique features

- Mode-crossings cause gaps
- Resolution not adequate to see excluded candidates
- Jagged edge due to performance of quantum amplifier

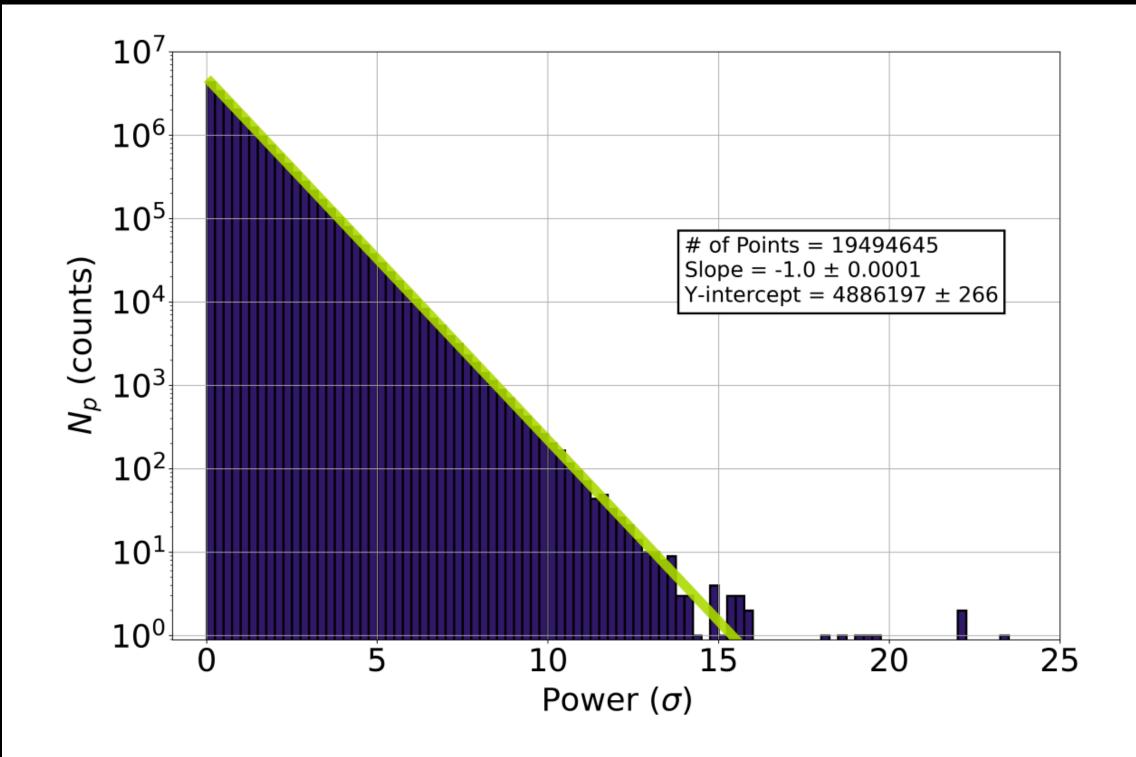


Discussion Questions

- Exclusion limit plots contain many assumptions
 - Are there ways to improve what is communicated in the plots?
 - Should we eliminate some assumptions?
 - How to have a coherent approach between groups?



High Resolution Search



Time-series

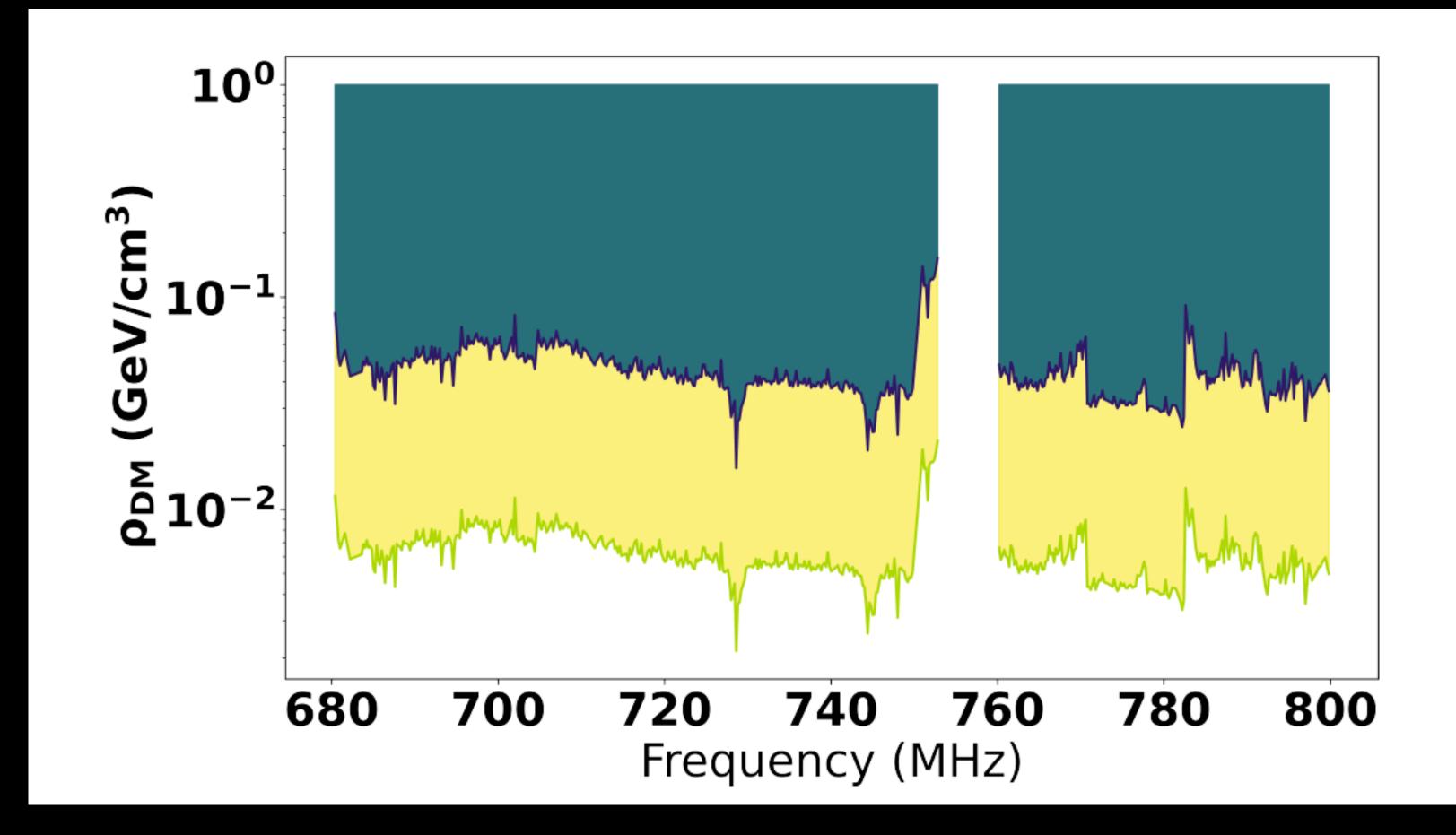
Sensitive to non-virialized axions

 Sensitive to frequency modulation from orbital and rotational motion

• 10 mHz native bin width



High Resolution Search



Legend

- Teal: DFSZ assumed
- Yellow: KSVZ assumed

No line-shape implied; monochromatic tone only

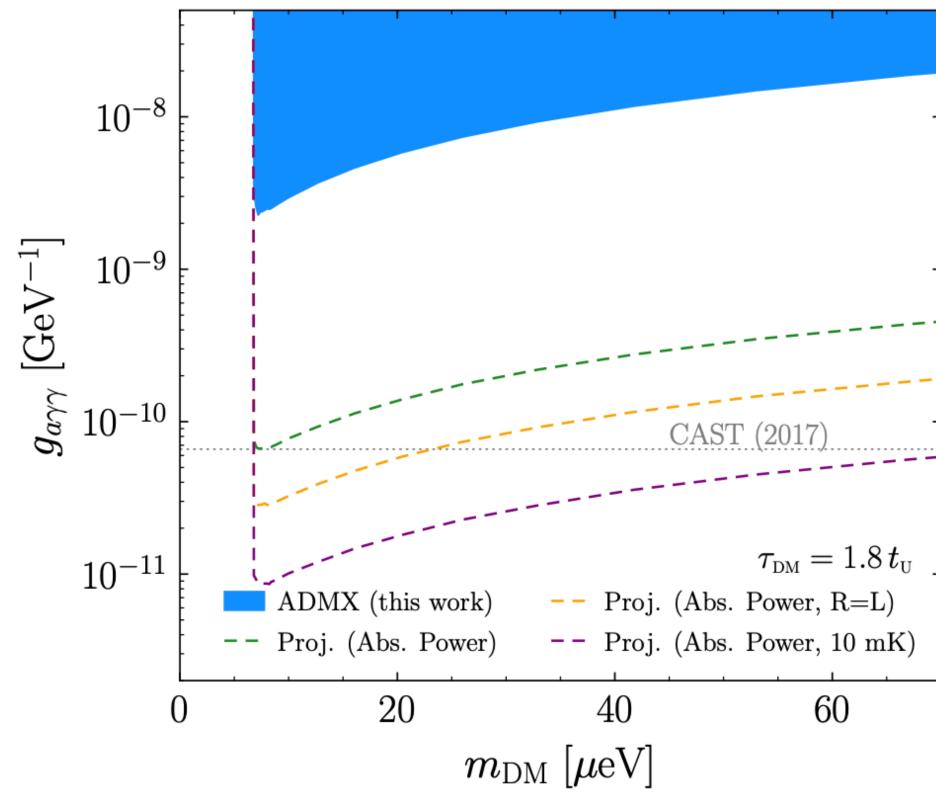


Cosmic Axion Background

Signal: Broadband amplitude modulation

Nitta, T., et al. "Search for the Cosmic Axion Background with ADMX." arXiv preprint arXiv:2303.06282 (2023).

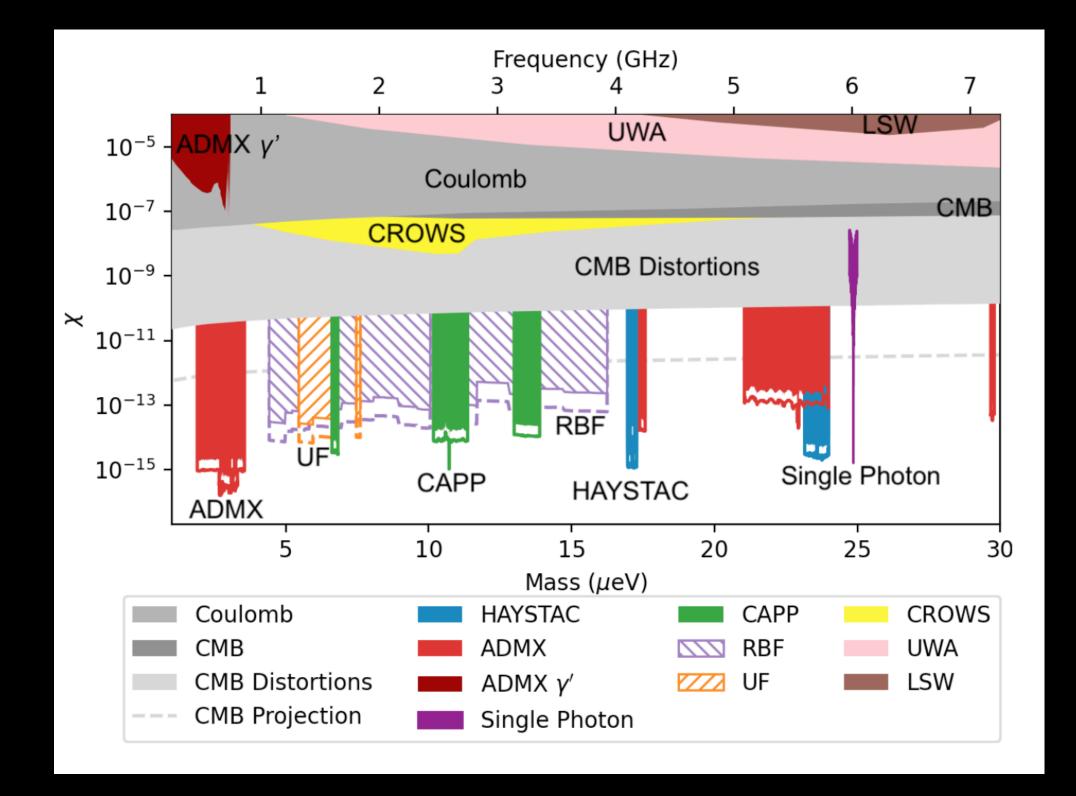






Hidden Photon Searches

- Hidden photon search does not require a magnetic field
- Simple scaling between axion and hidden photon search



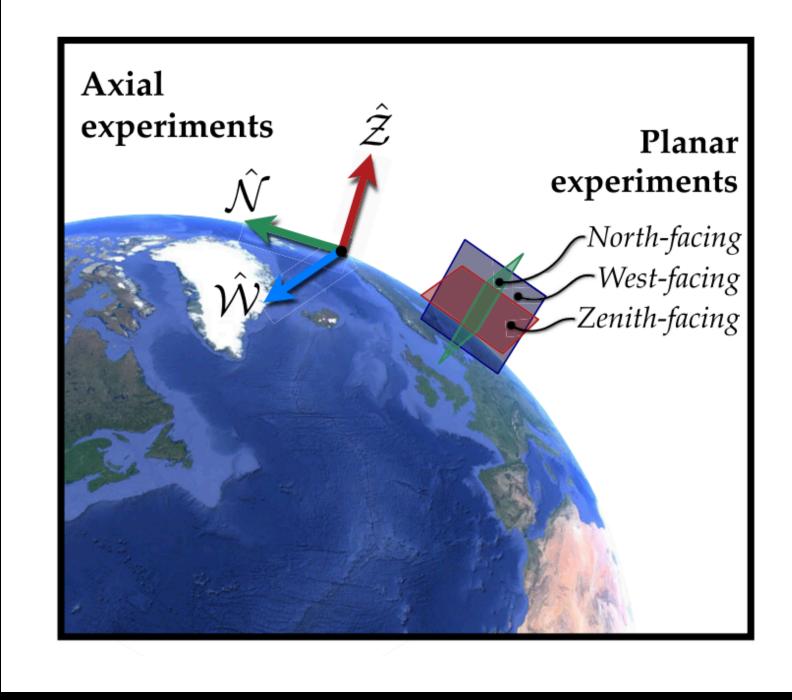
Ghosh, Sumita, et al. "Searching for dark photons with existing haloscope data." *Physical Review D* 104.9 (2021): 092016.



Hidden Photon Searches

- More sophisticated search can account for detector orientation
- Intentional rescanning such that timing can be used to improve detector sensitivity
- Challenging due to rescan process

Detector-centric coordinates



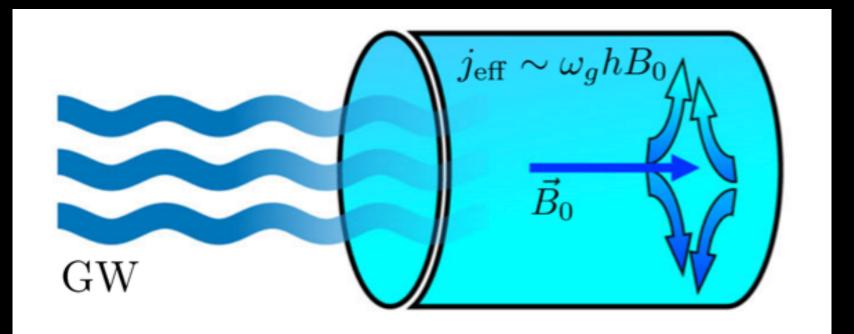
Caputo, Andrea, et al. "Dark photon limits: A handbook." *Physical Review D* 104.9 (2021): 095029.

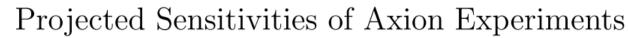


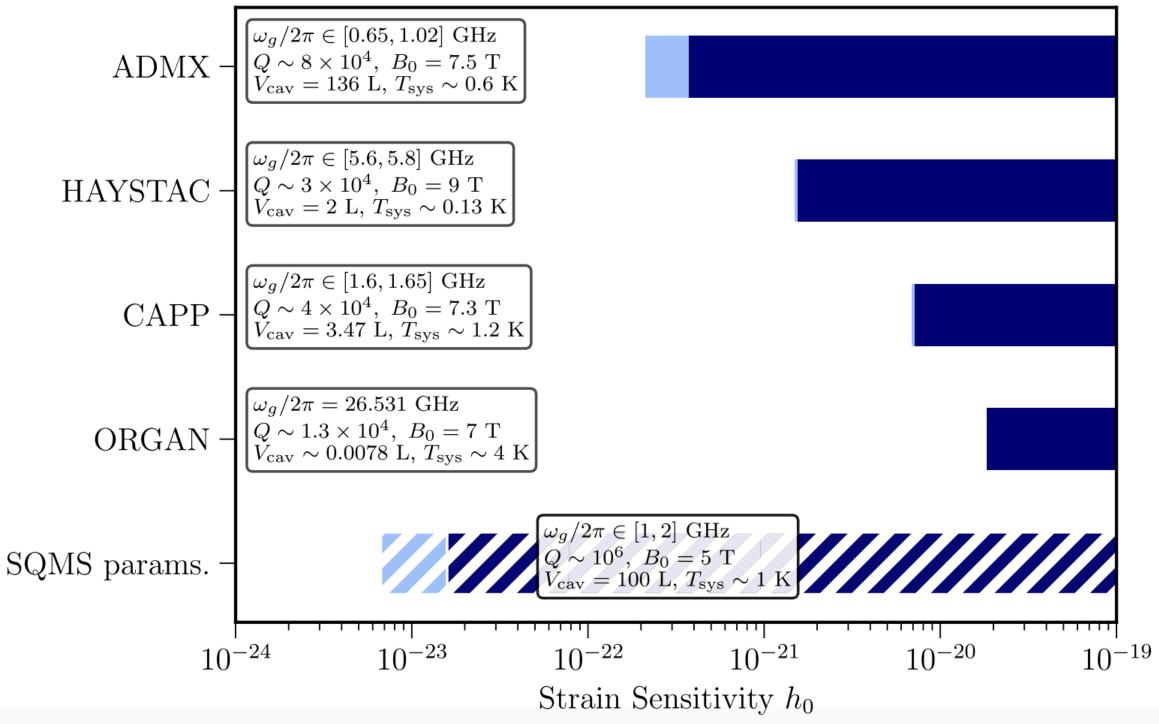
Other offline analyses

High Frequency Gravitational Wave Searches

Signal: Broadband amplitude modulation







Berlin, Asher, et al. "Detecting high-frequency gravitational waves with microwave cavities." Physical Review D 105.11 (2022): 116011.



Discussion Questions

- Operations is driven by the Standard Halo Model.
 - Are there other models we should take into account?
 - At what cost?

