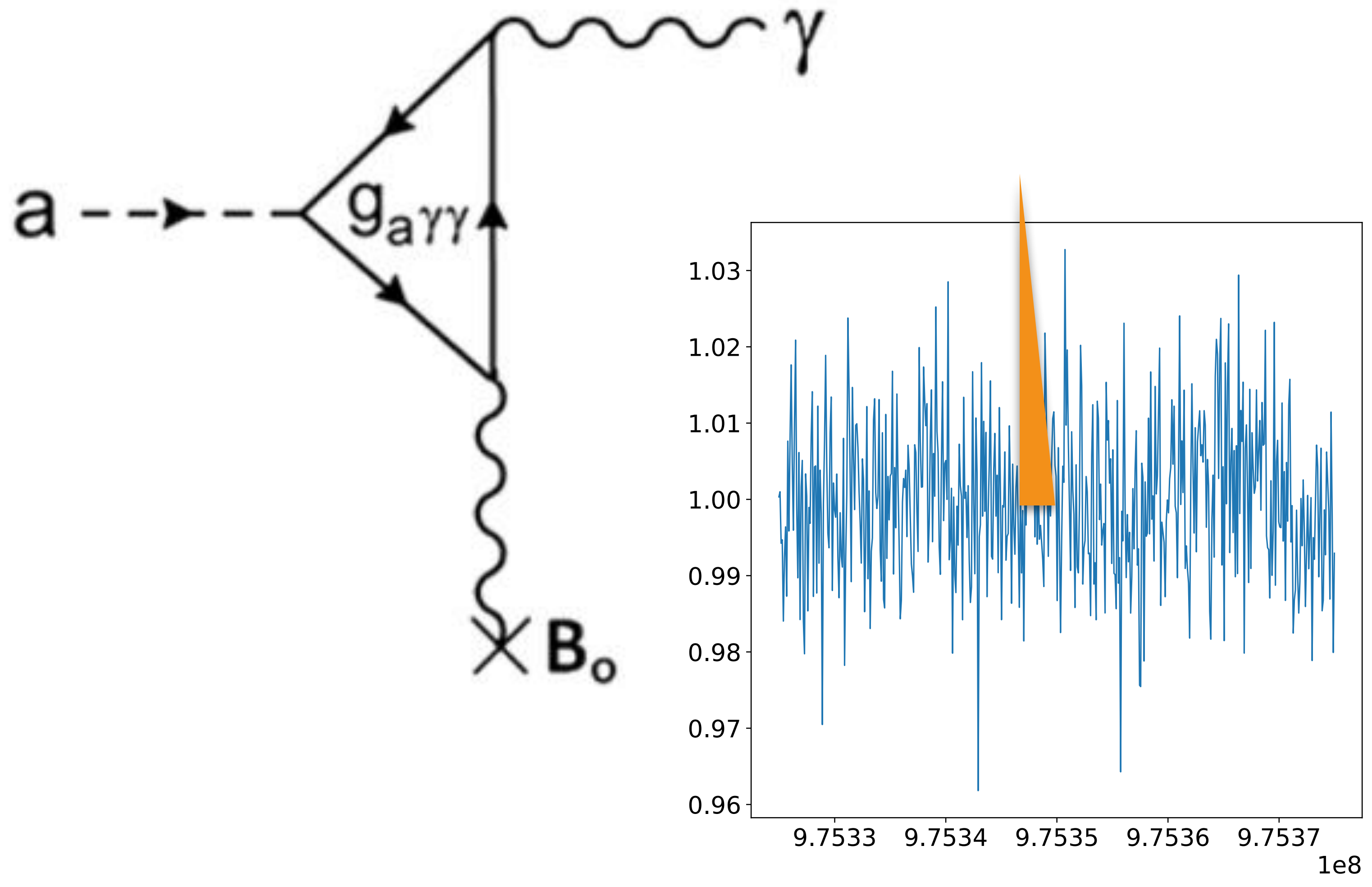
Medium Resolution Data Analysis

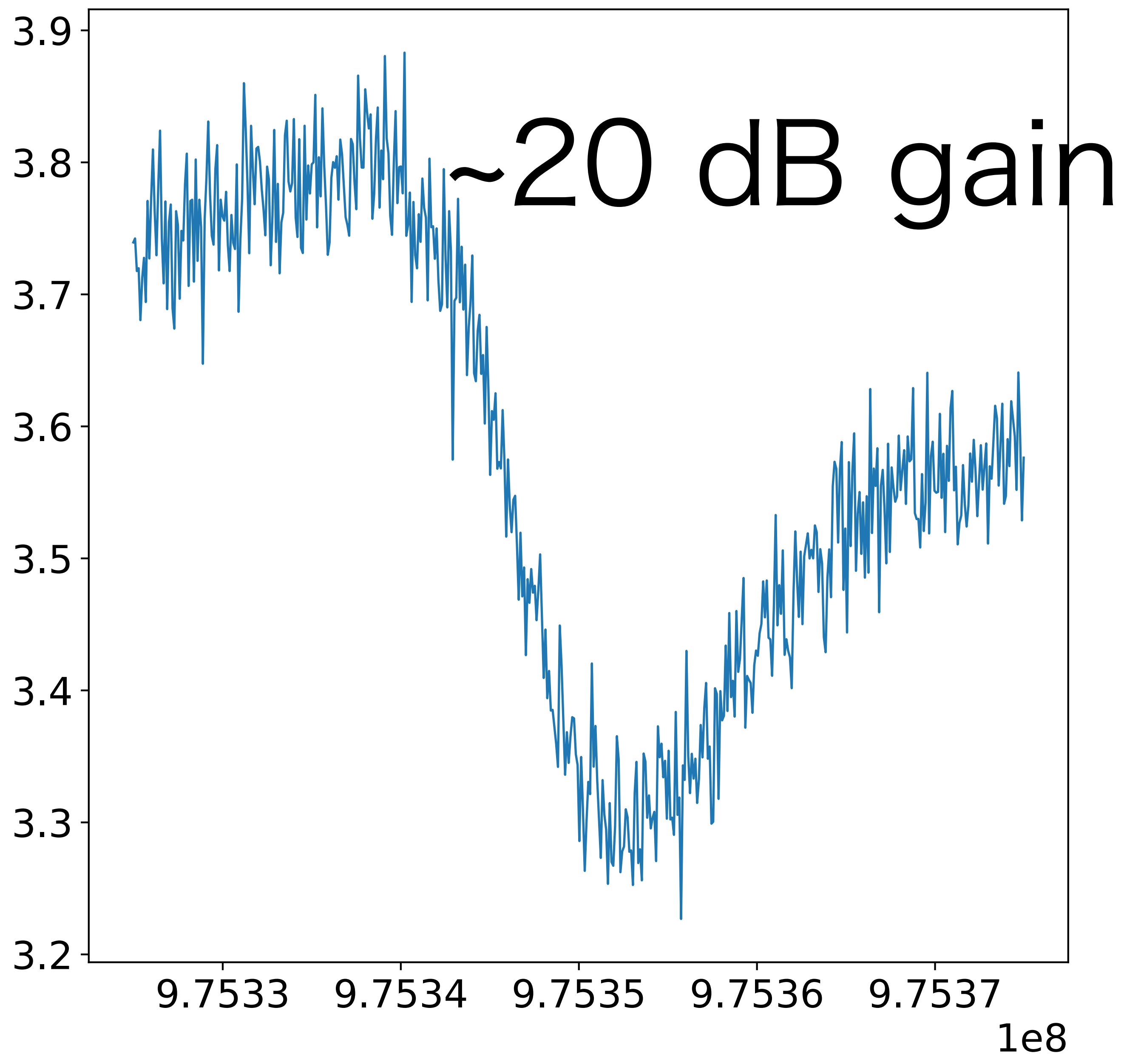
Nov 16, 2020
ADMX Collaboration Virtual Meeting
Tatsumi Nitta @ UW

Concept

Axion converts into photon $\propto C_{010}B^2QV$

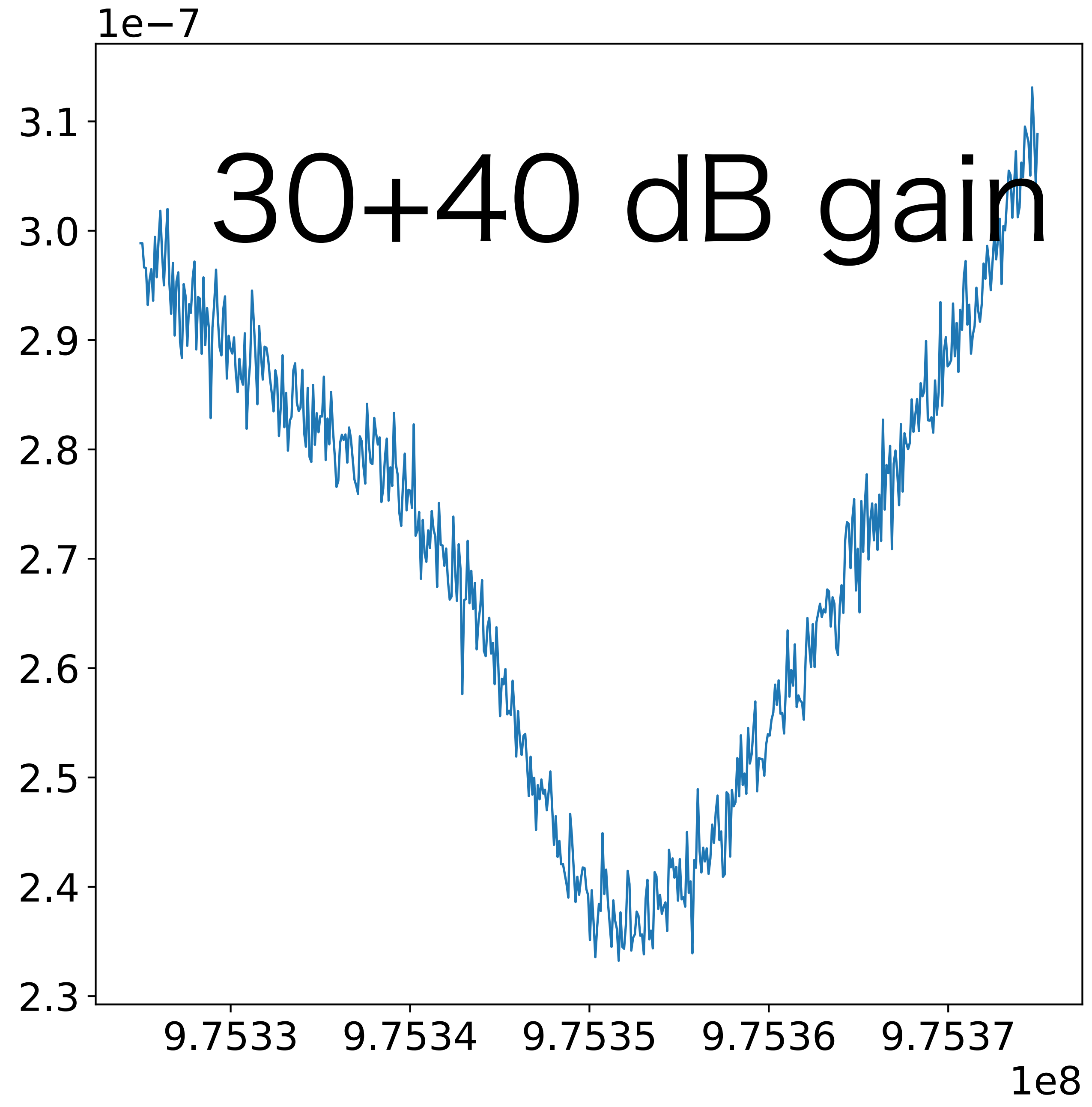


Spectrum after JPA



JPA standing wave distortion

Spectrum at digitizer



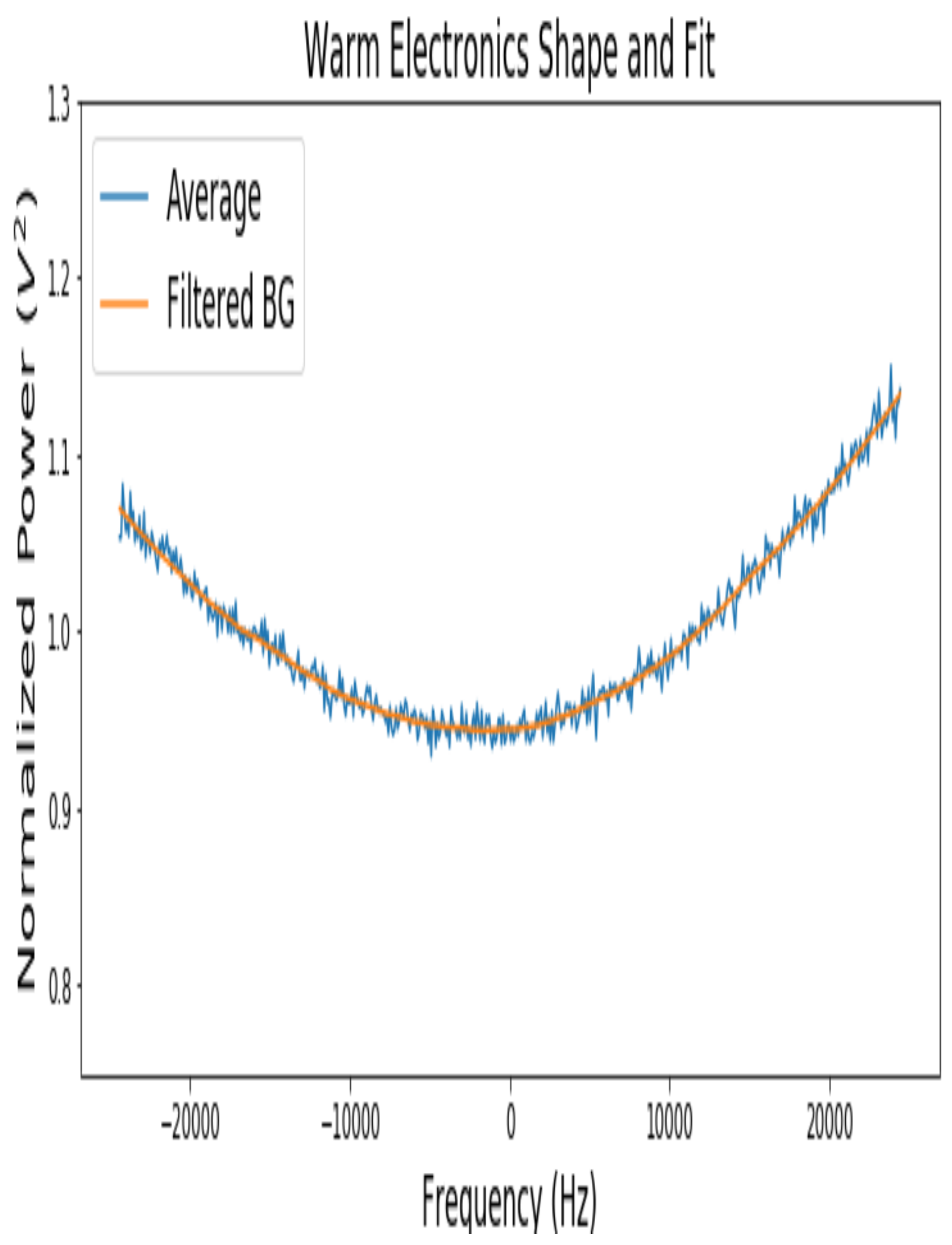
Warm electronics distortion

Want to back to spectrum right after conversion for both shape and scale

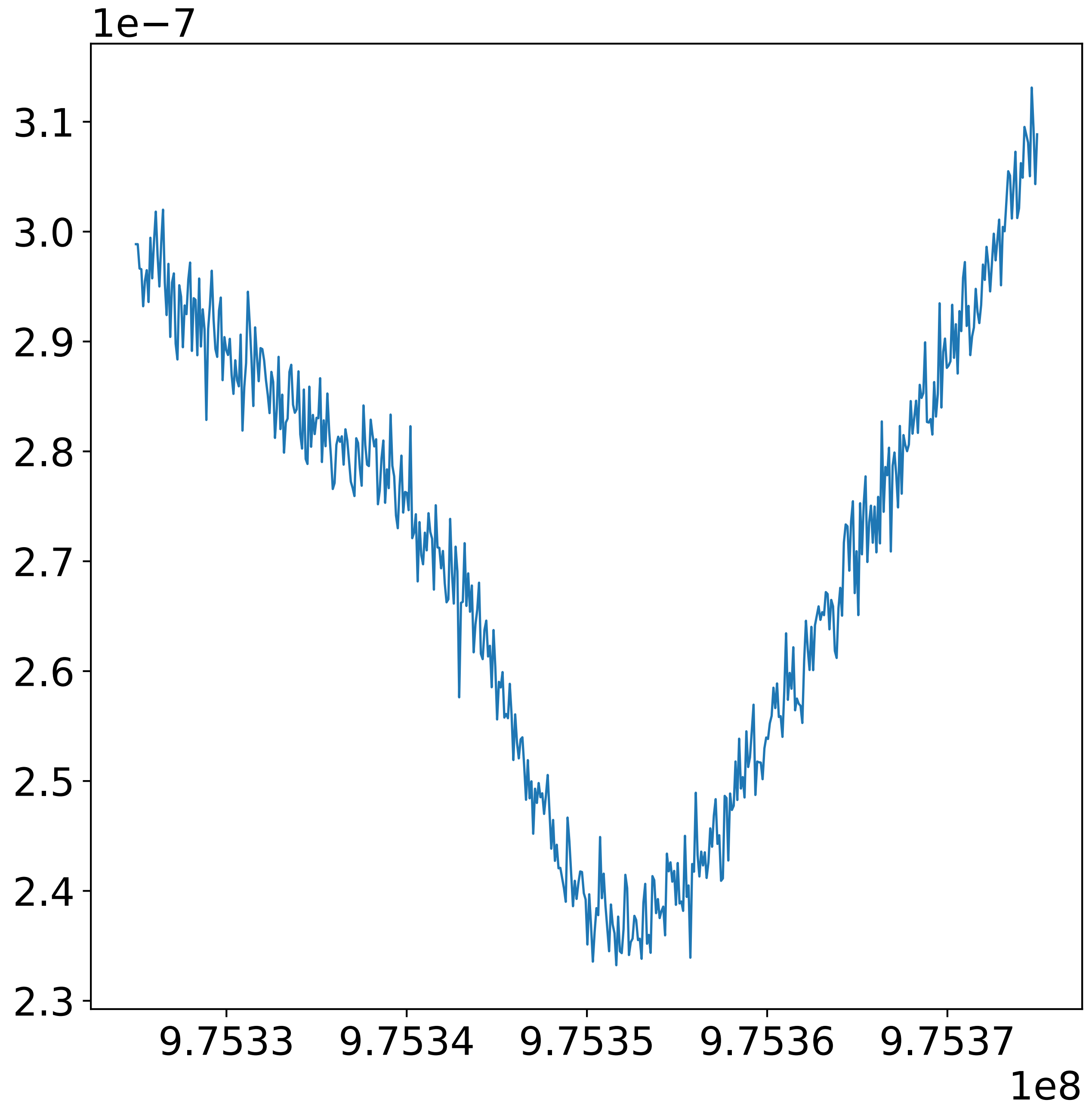
Warm Electronics Shape

Warm electronics shape (including HFET) is very stable.

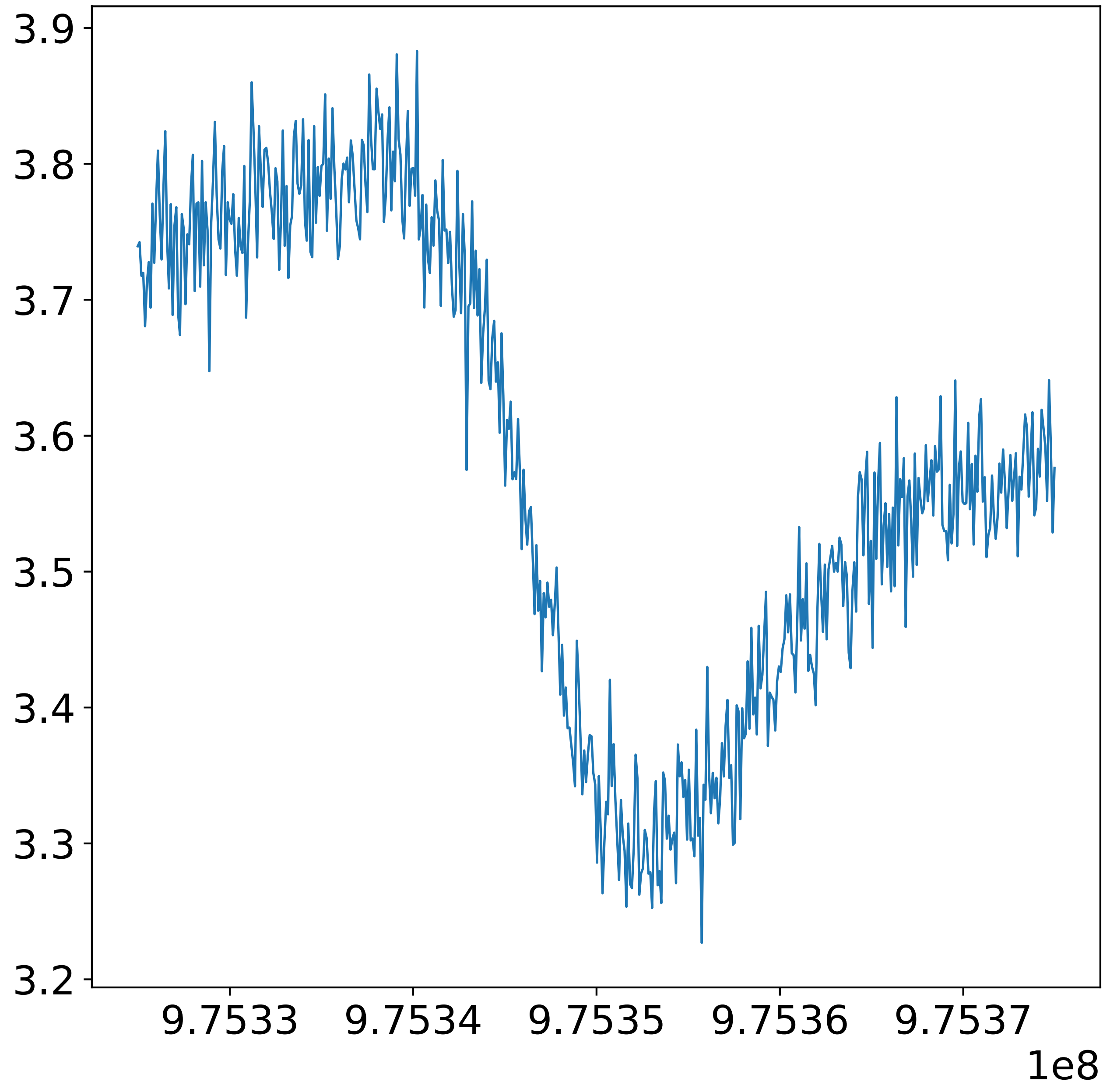
Take an average of several digitizer measurements with JPA off.



f_{receiver}



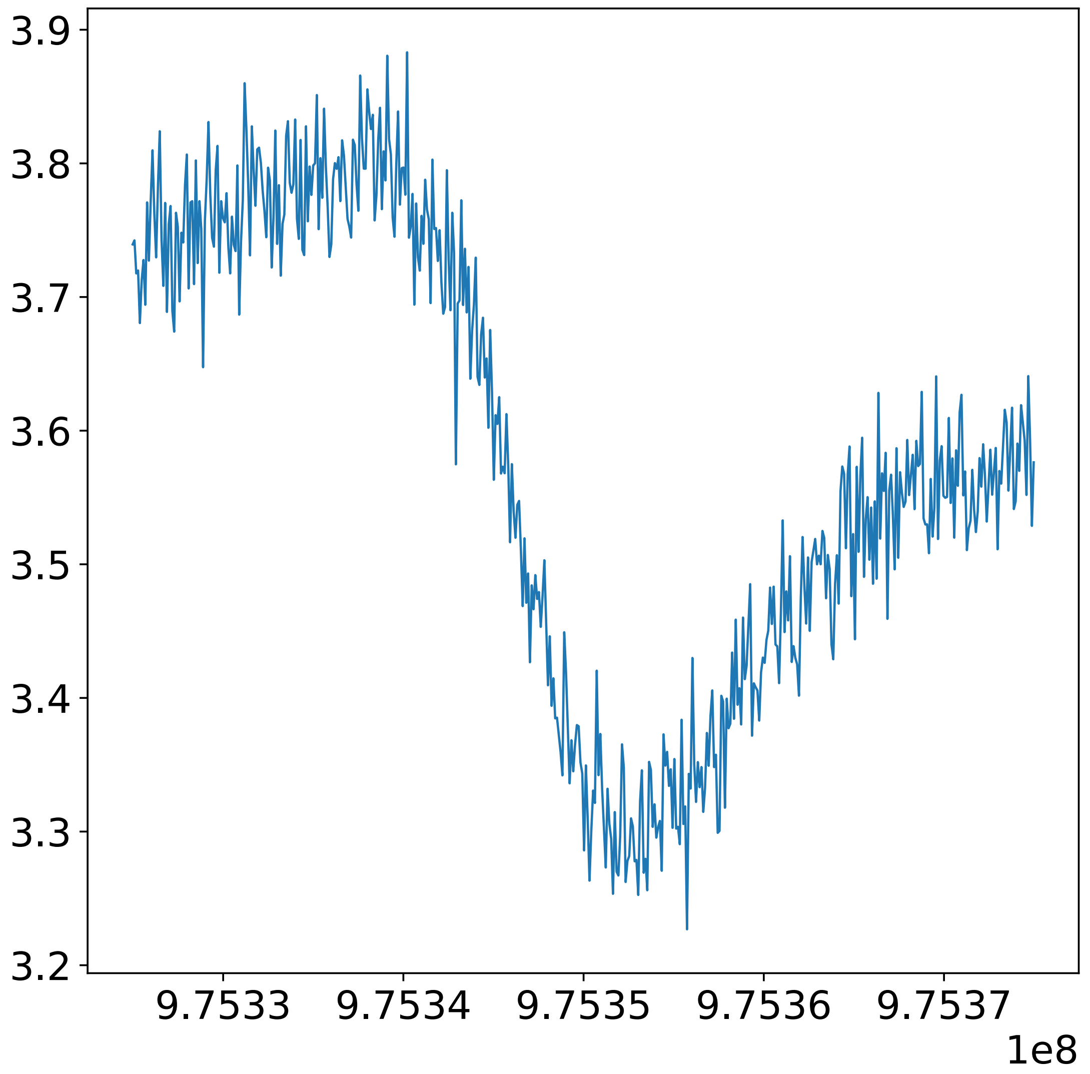
P_{raw}

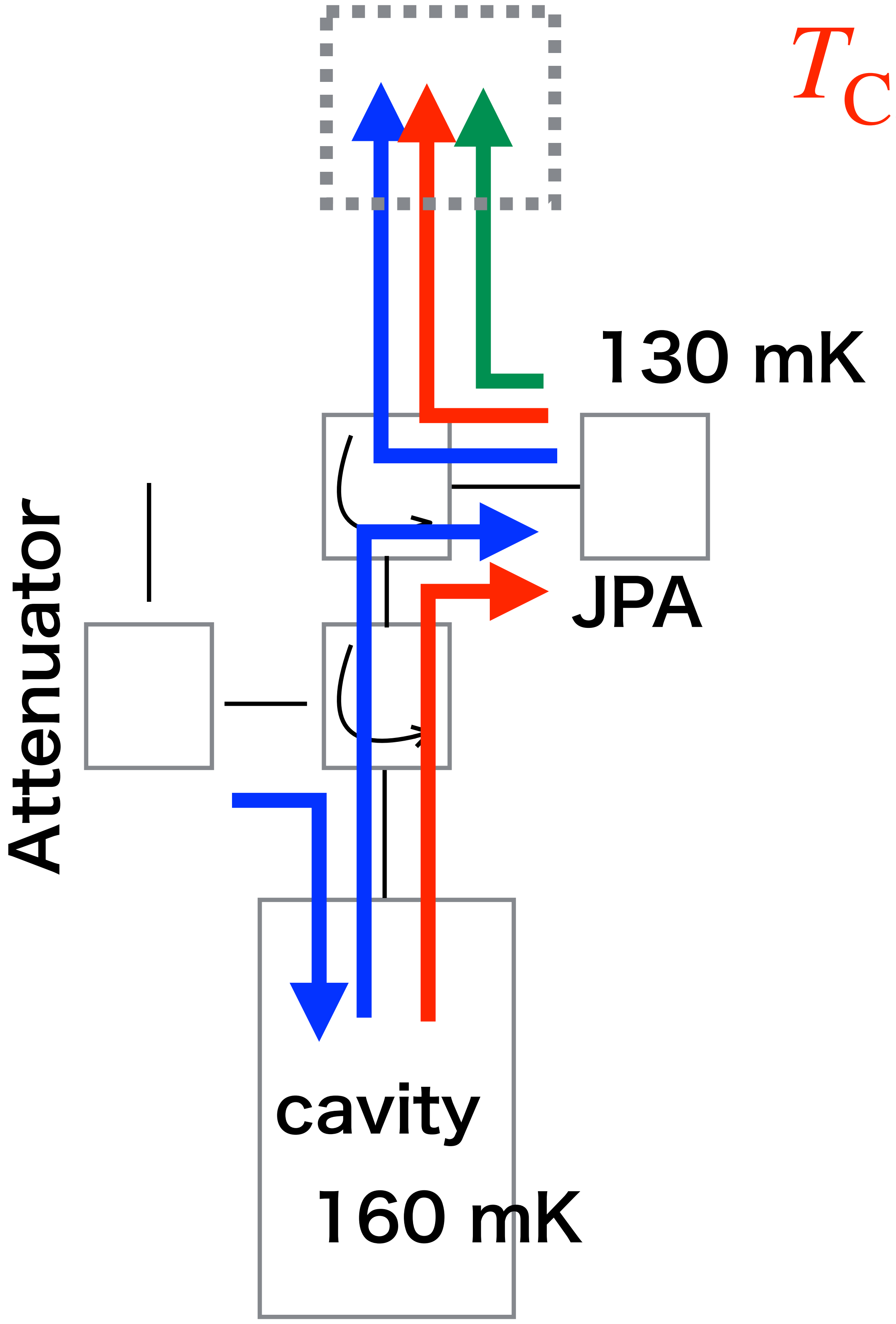


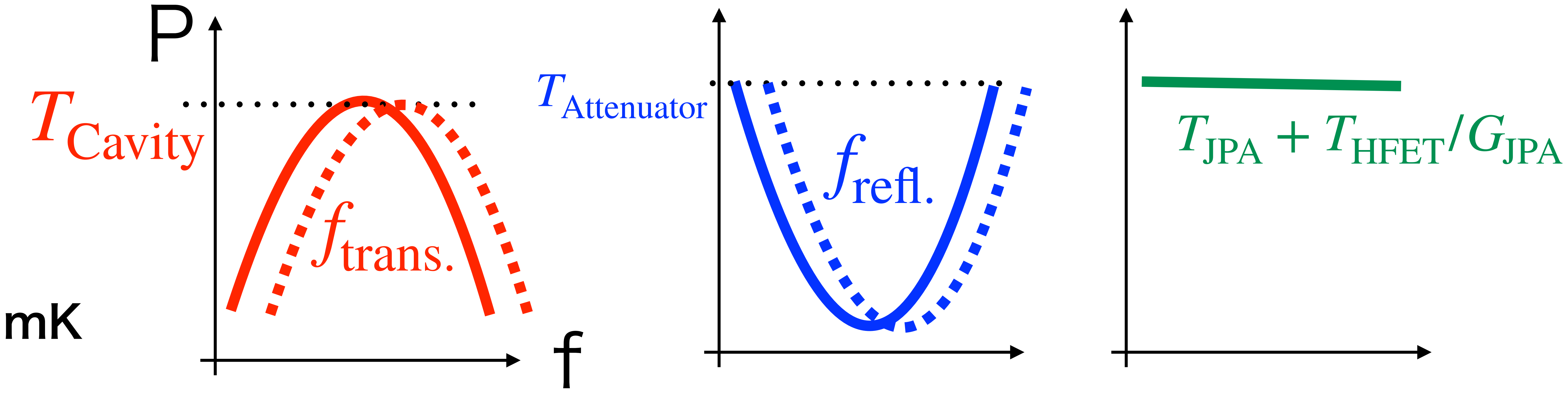
$P_{\text{raw}}/f_{\text{receiver}}$

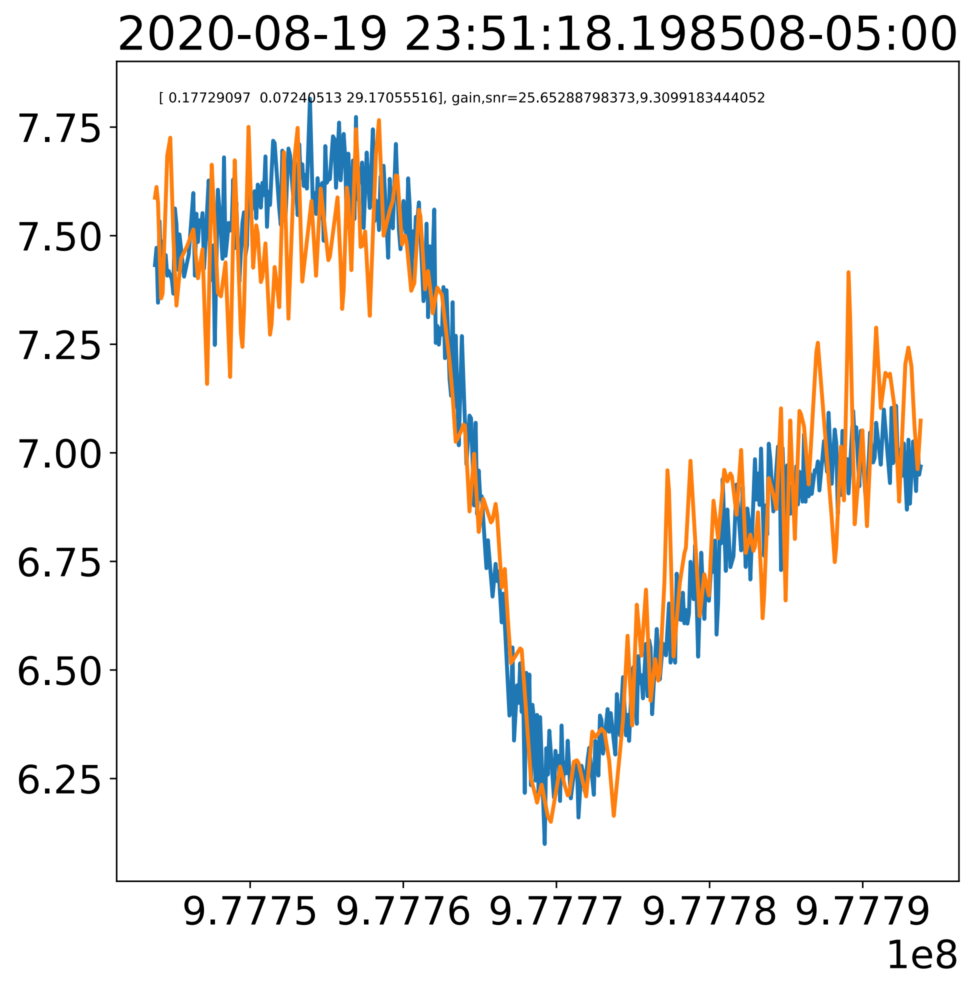
JPA Shape: Model

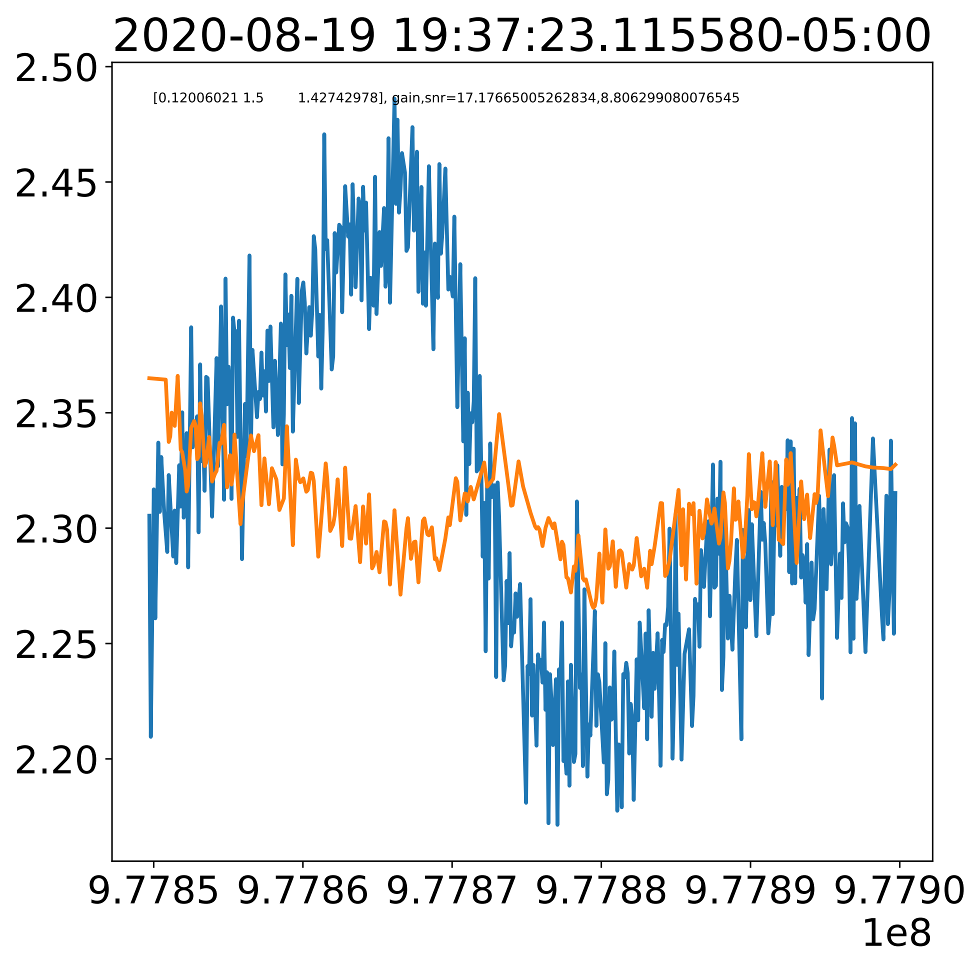
$P_{\mathrm{raw}}/f_{\mathrm{receiver}}$







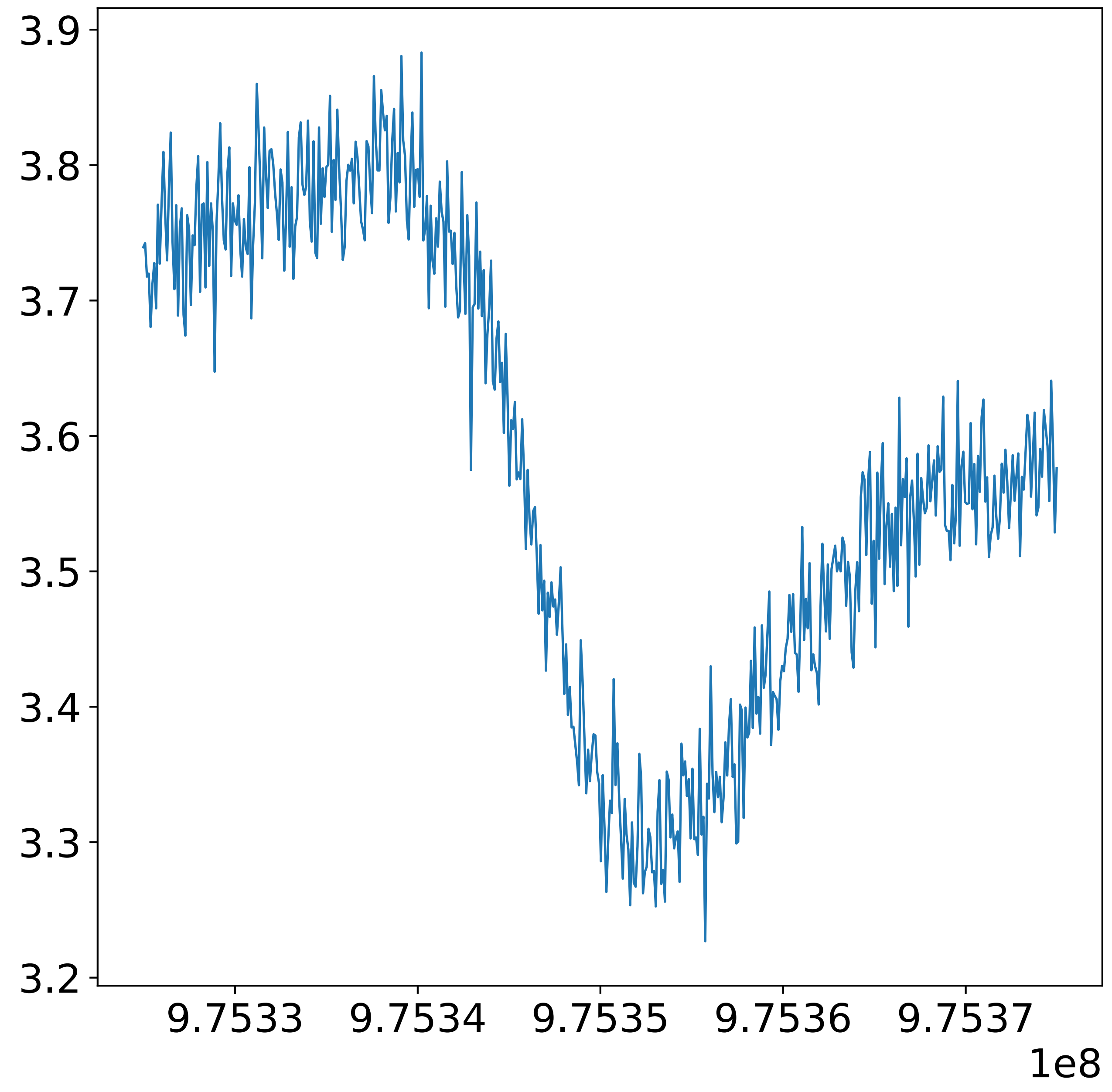




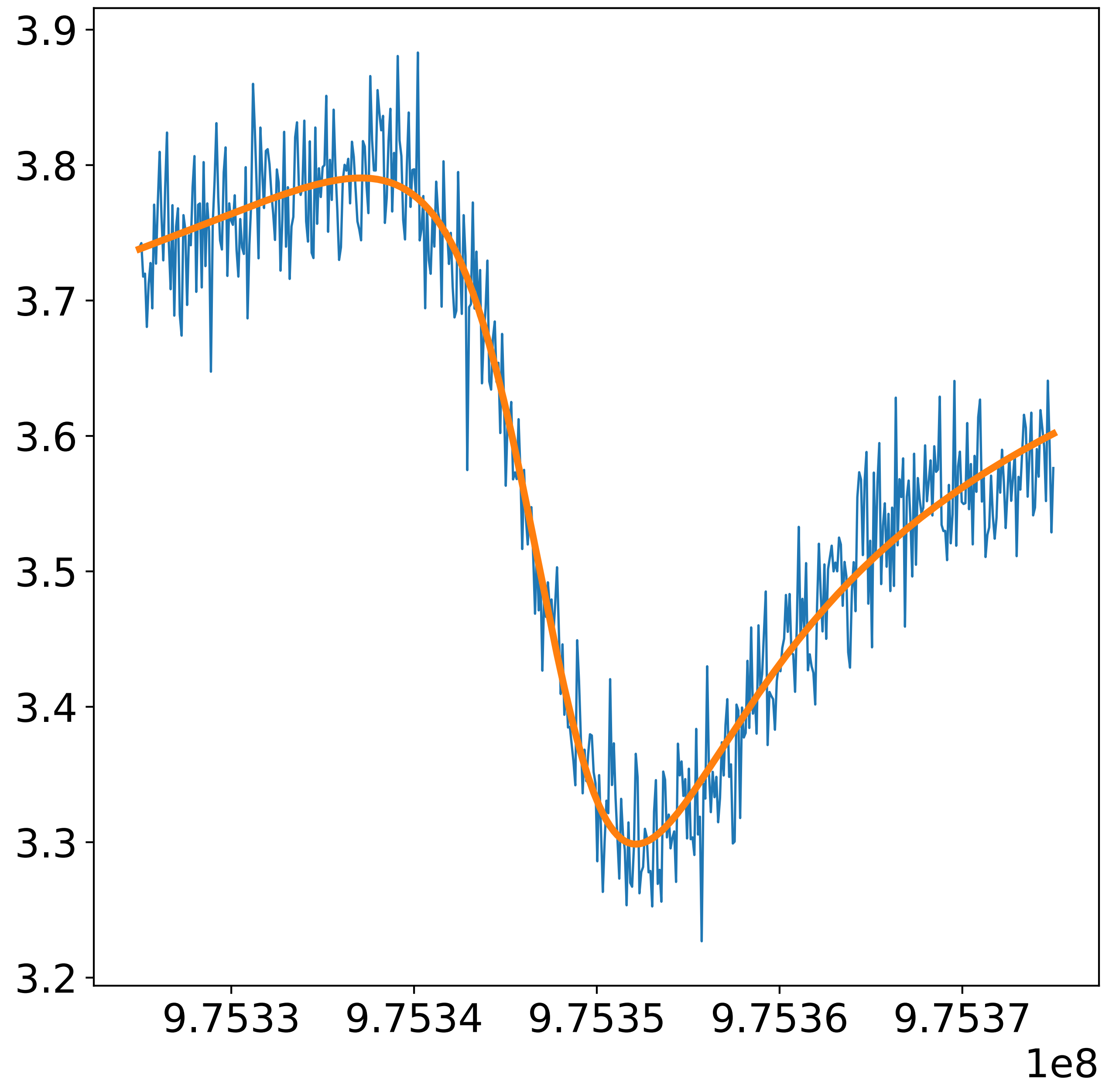
Sometimes can be modeled.

But not always success…

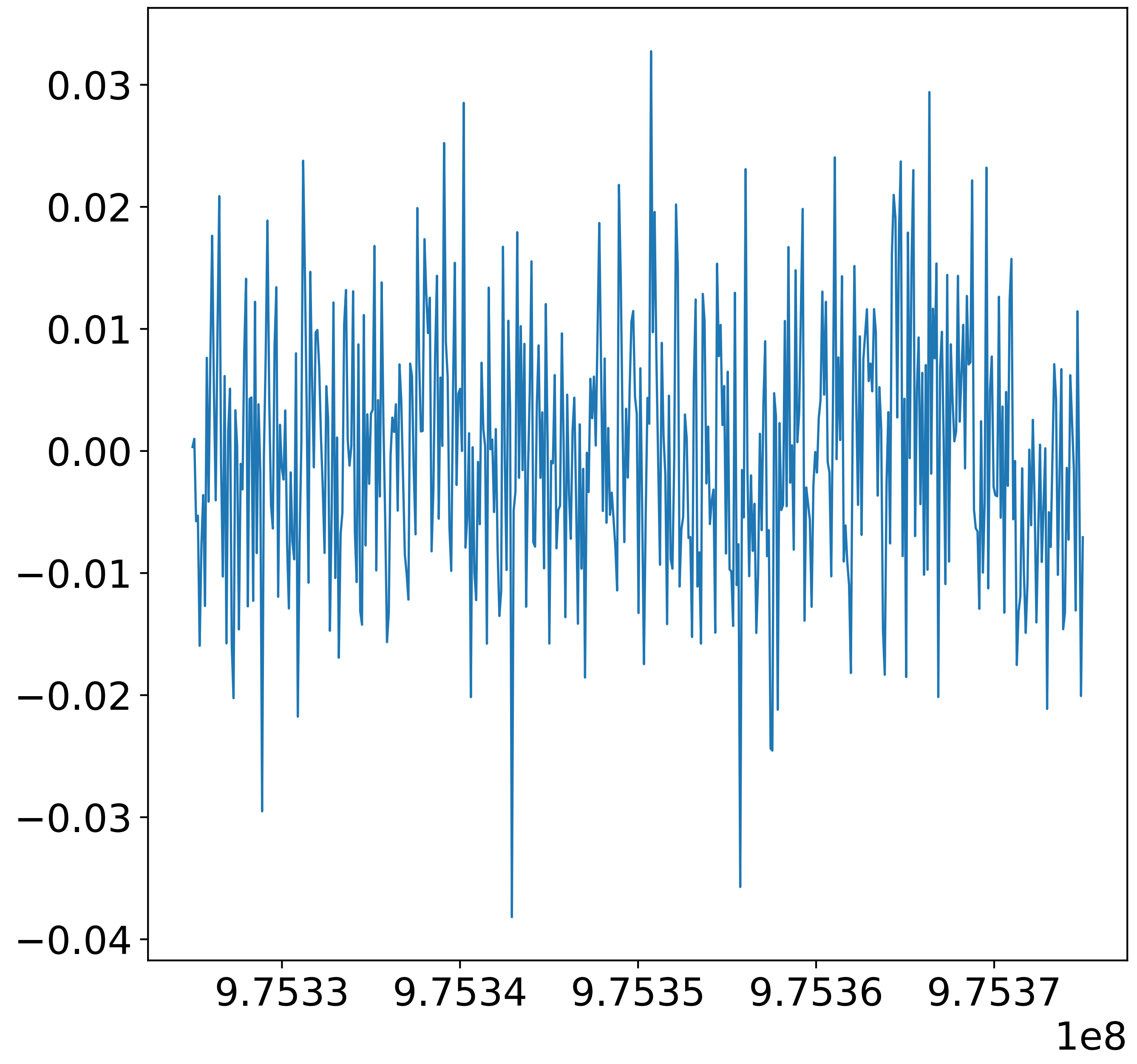
JPA Shape: pade approximation



$$P_{\text{raw}}/f_{\text{receiver}}$$



$$f_{\text{pade}}$$



$$P_{\text{raw}}/(f_{\text{receiver}}f_{\text{pade}}) - 1$$

$$f_{\text{pade}}(x) = \frac{a + bx + cx^2 + dx^3}{1 + ex + fx^2}$$

Now we get correct shape
(Scale is normalized
by standard deviation)

Scaling spectrum

- Assume spectrum is made by background + maybe a few signals (negligible). standard deviation should be $k_b T_{\mathrm{sys}} b$ [W]
- Signal is enhanced by cavity, magnetic field, form factor,⋯.

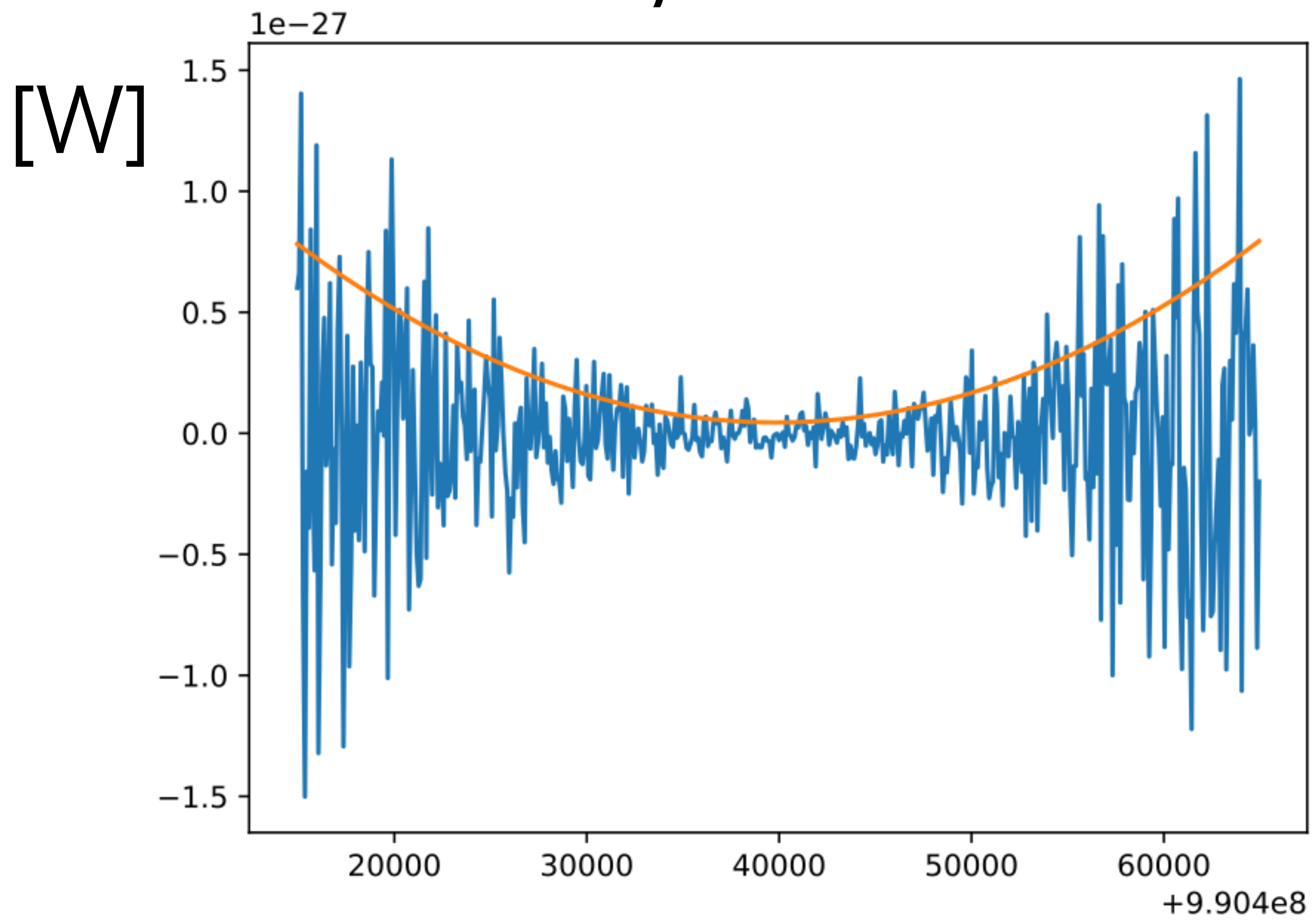
Multiply $$k_b T_{\mathrm{sys}} b / (\frac{\beta}{1+\beta} C_{010} V Q B^2 f_{\mathrm{lorentzian}})$$

- Those values are smoothed 15 or 30 minutes.
- Cut abnormal parameters

	cut value
Q	[20000, 160000]
χ2/NDF	<20
Tsys	[0.1, 20] K
SNRI	<40 dB
f0	[750, 1022] MHz

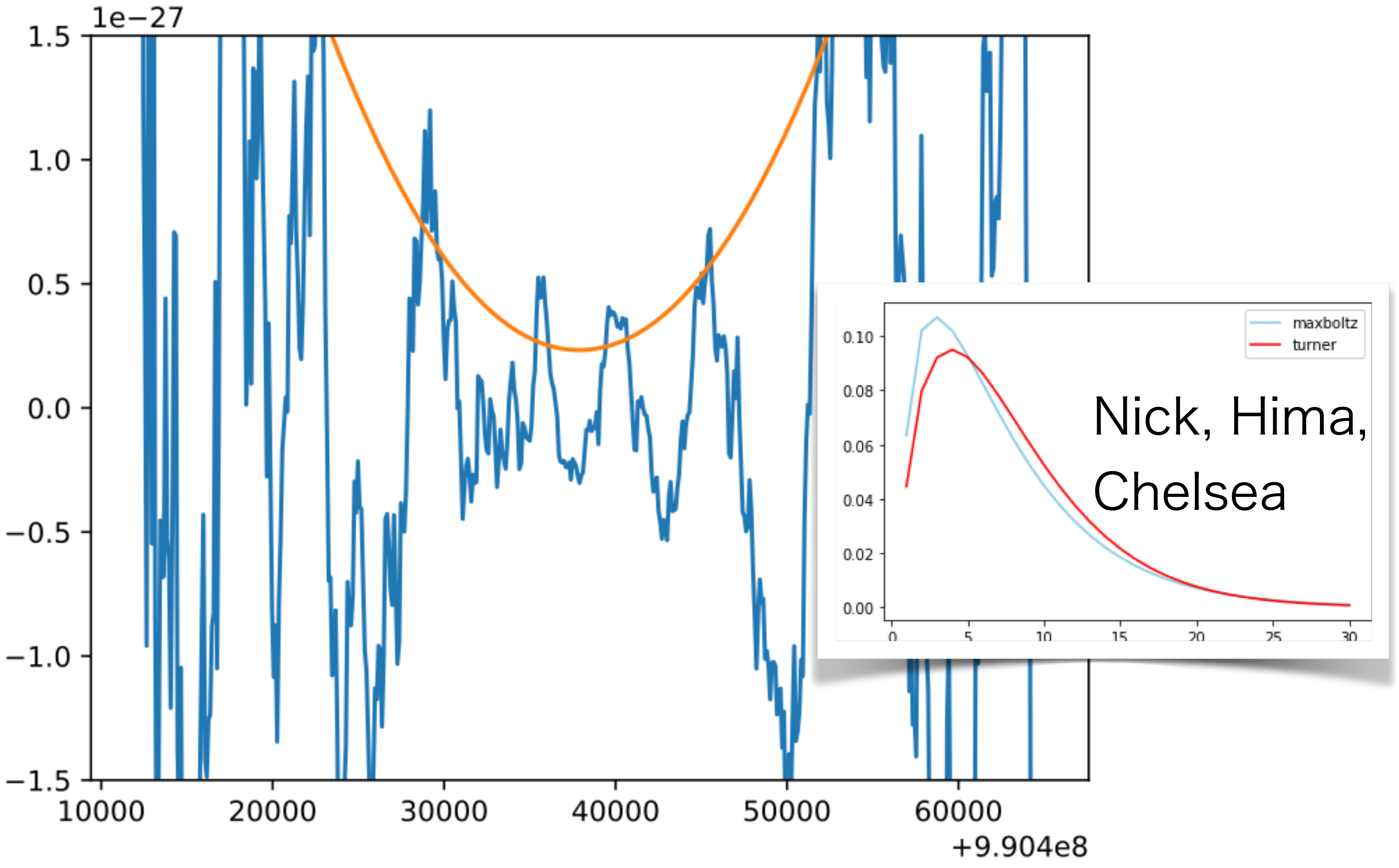
Scale spectrum

$$P_{\mathrm{raw}}/(f_{\mathrm{receiver}} f_{\mathrm{pade}}) - 1 \ \times$$
$$k_b T_{\mathrm{sys}} b / (\frac{\beta}{1+\beta} C_{010} V Q B^2 f_{\mathrm{lorentzian}})$$



Finally we got correct scale and shape.

And optimal filtering: folding with predicted axion spectrum



Nick, Hima, Chelsea

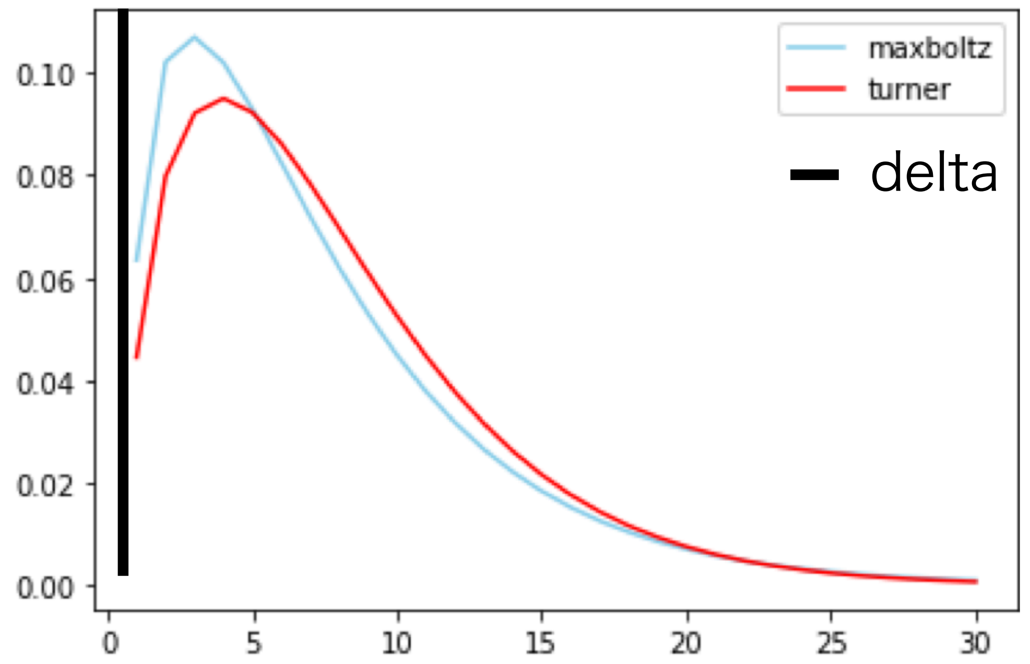
Grand Spectrum

Combining each spectrum, then we get one grand spectrum.

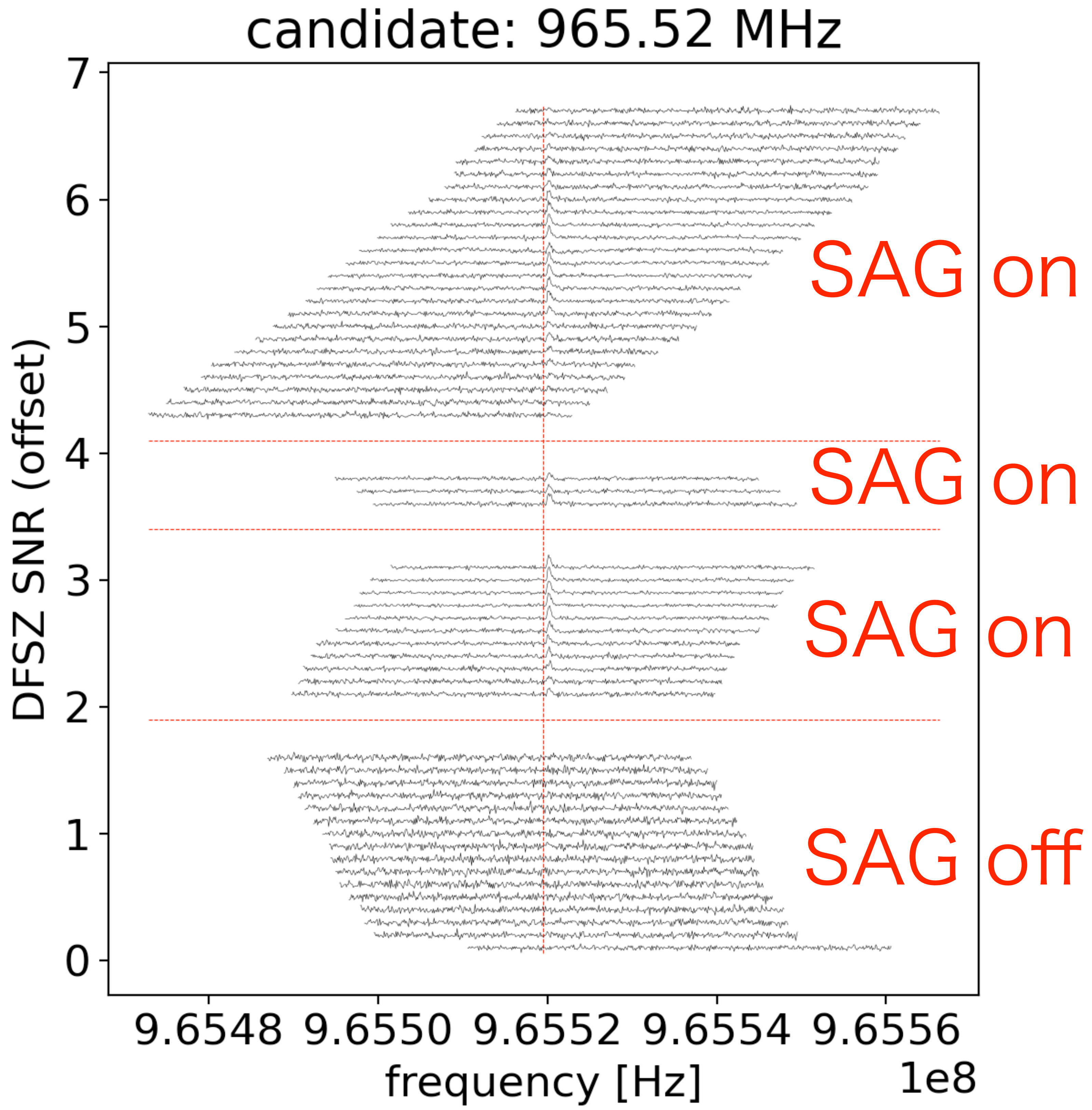
Find axion from that or

Get limit to compare it to expected axion power

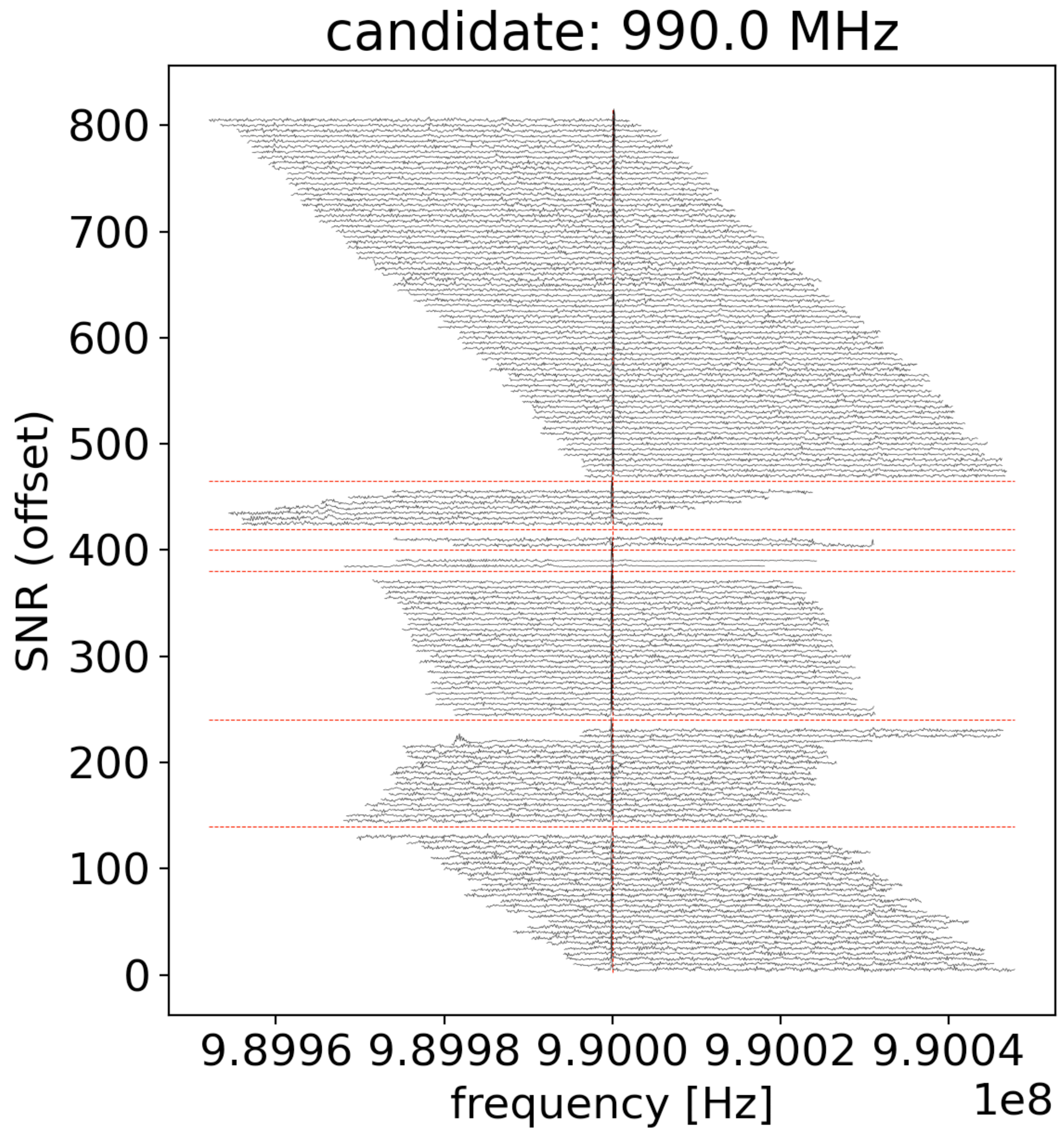
Candidate Inspection



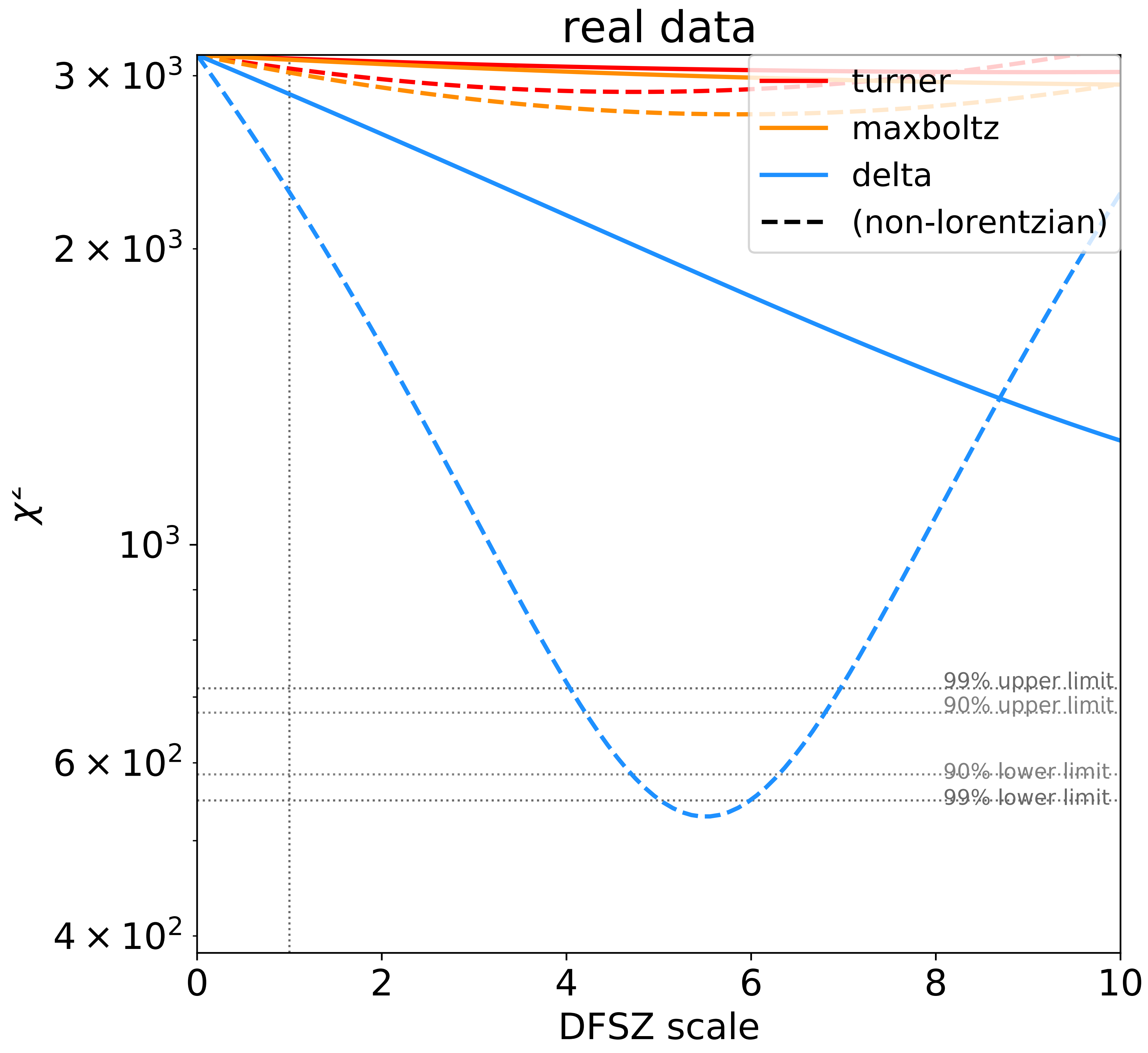
SAG



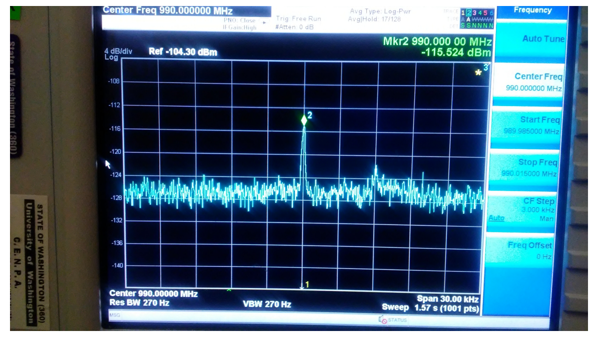
Axion?



Looks RFI

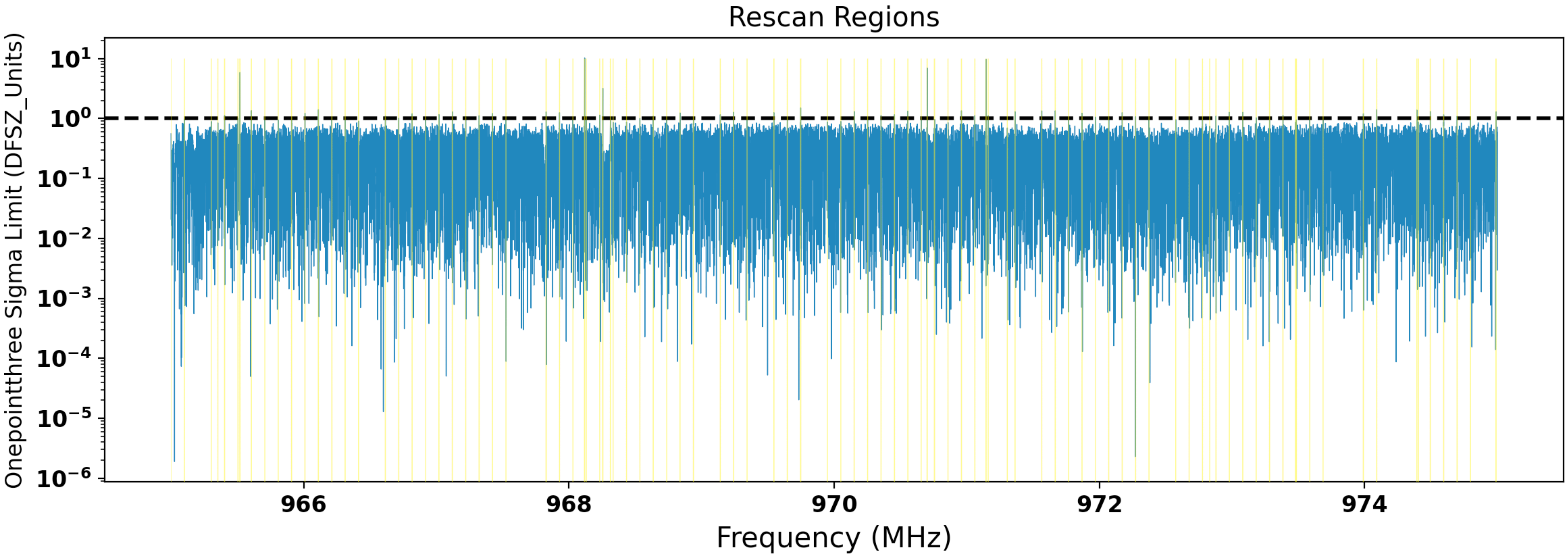


must be RFI



Software Synthetic Signals

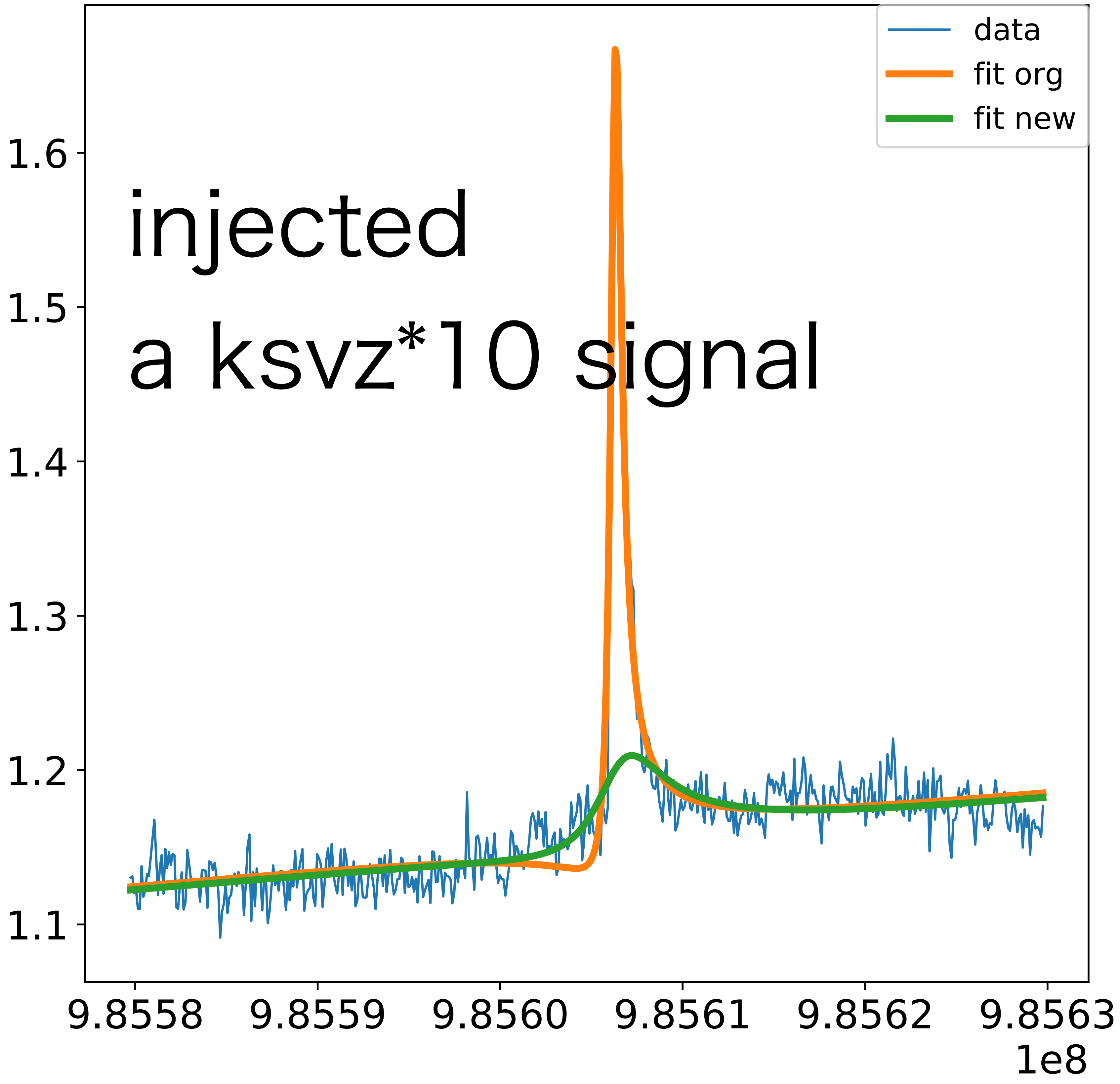
To check we can detect signal with the analysis method,
we injected software synthetic signals into raw data or simulation.



$\epsilon = N_{\mathrm{detect}}/N_{\mathrm{inject}} \sim 90\,\%$ $c_{\mathrm{fudge}} = P_{\mathrm{detected}}/P_{\mathrm{injected}} \sim 0.8$ for DFSZ signal

Improving Background Modeling

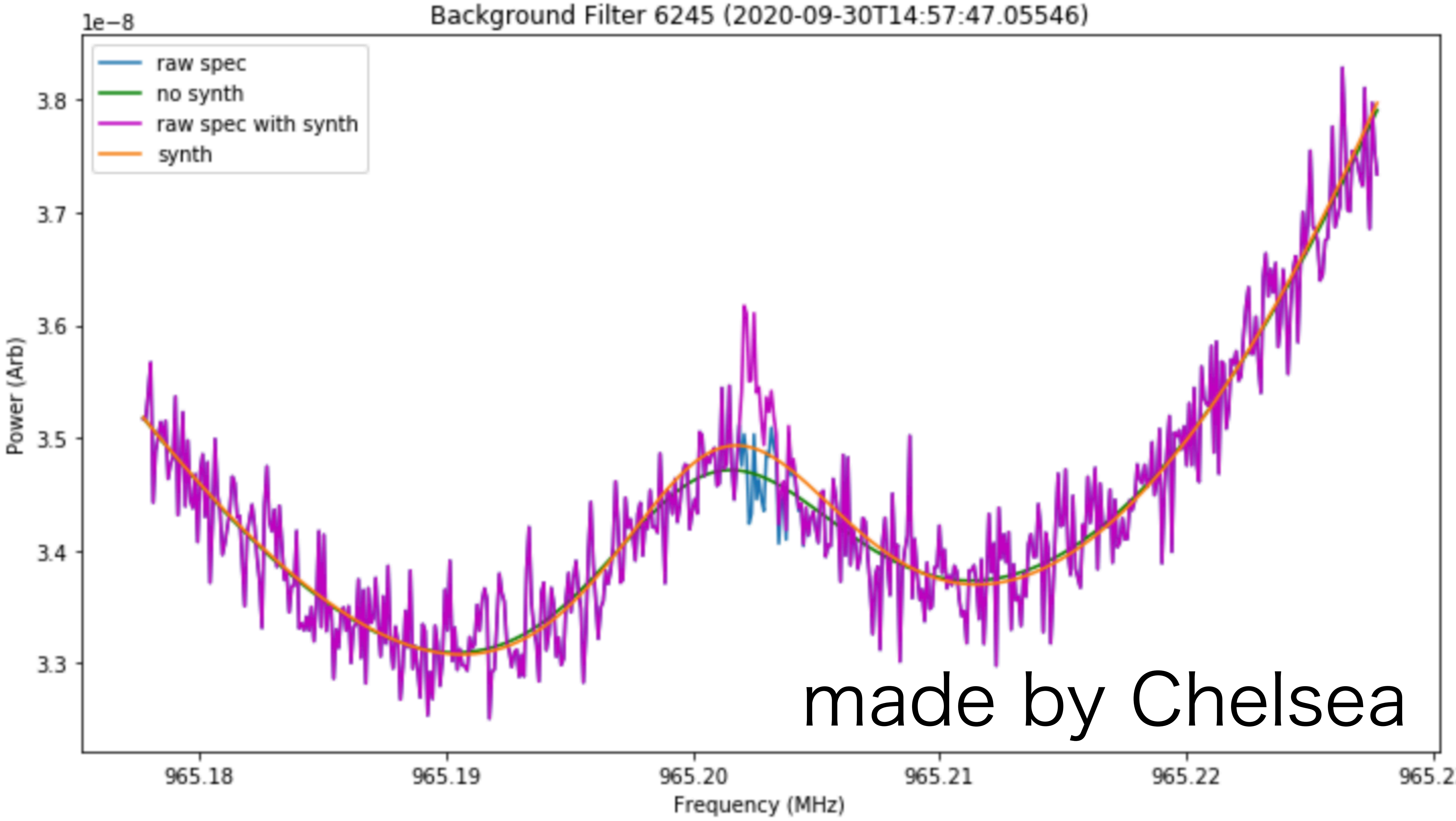
Signal distorts background estimation



injected
a ksvz*10 signal

New: Ignore significant peak

Distortion from DFSZ level isn't corrected by new pade filter.

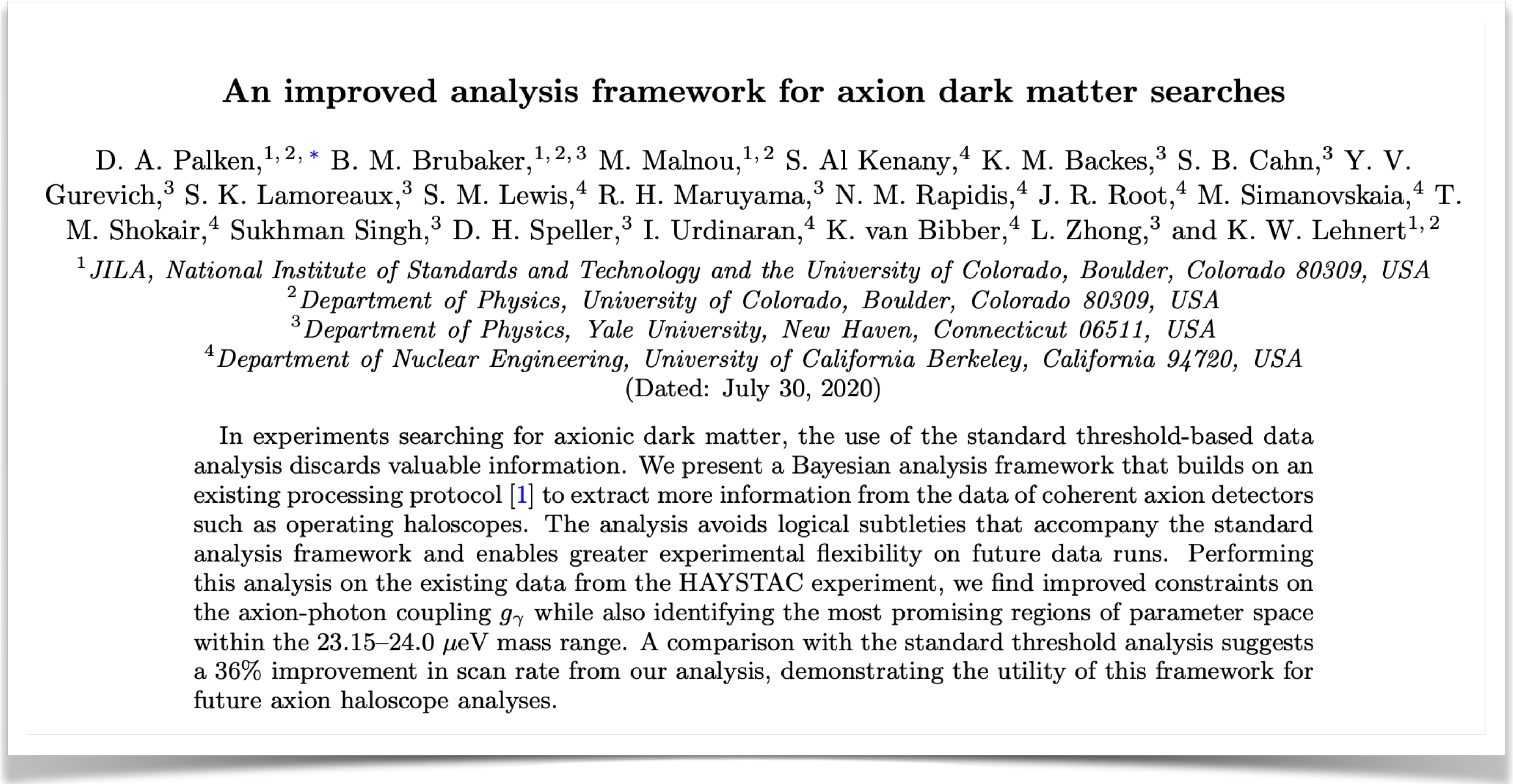


made by Chelsea

This is cause of fudge factor = 0.8
We're working on it

Bayesian Analysis

HAYSTAC people uses Bayesian based analysis framework.



An improved analysis framework for axion dark matter searches

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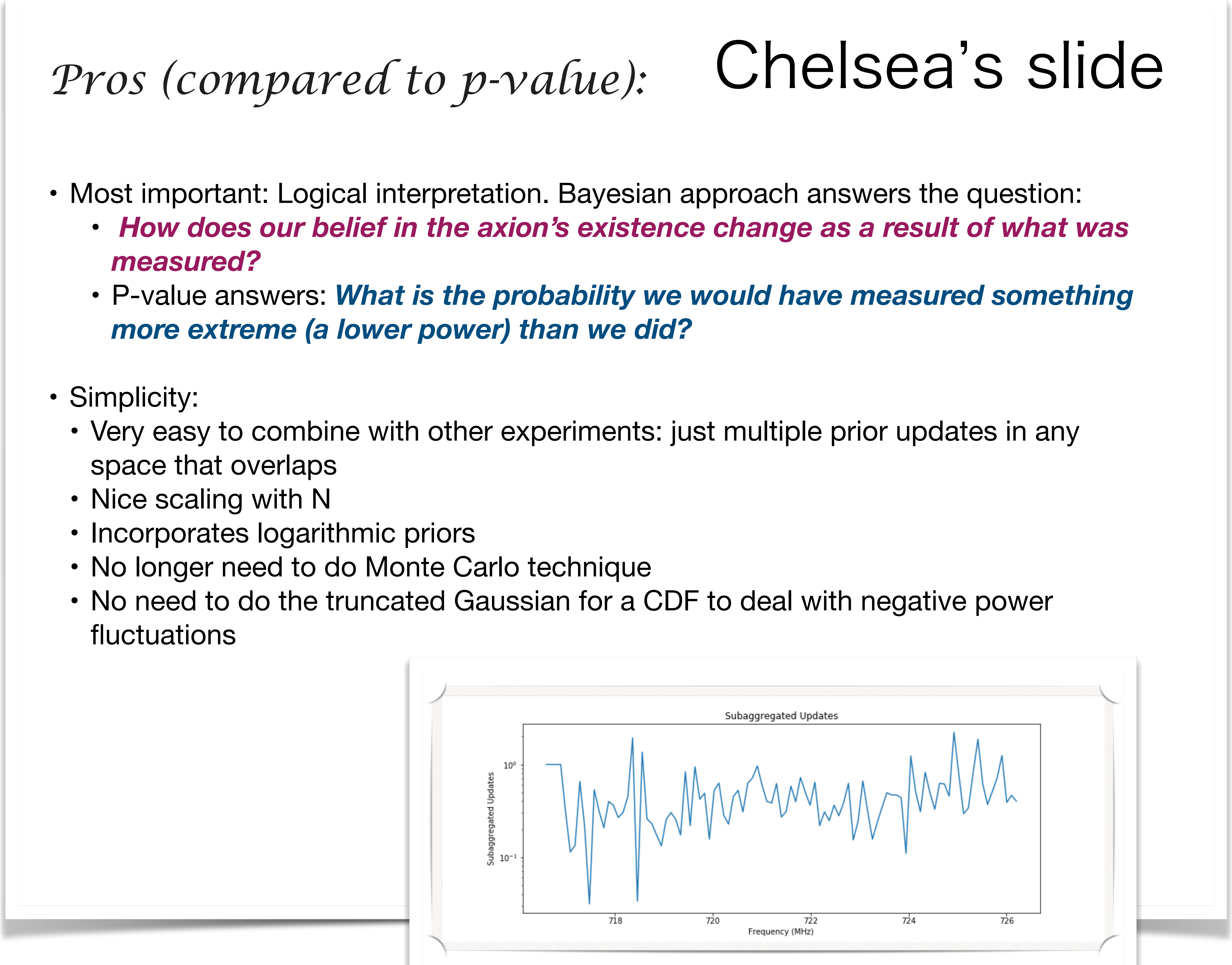
(Dated: July 30, 2020)

In experiments searching for axionic dark matter, the use of the standard threshold-based data analysis discards valuable information. We present a Bayesian analysis framework that builds on an existing processing protocol [1] to extract more information from the data of coherent axion detectors such as operating haloscopes. The analysis avoids logical subtleties that accompany the standard analysis framework and enables greater experimental flexibility on future data runs. Performing this analysis on the existing data from the HAYSTAC experiment, we find improved constraints on the axion-photon coupling g_γ while also identifying the most promising regions of parameter space within the 23.15–24.0 μeV mass range. A comparison with the standard threshold analysis suggests a 36% improvement in scan rate from our analysis, demonstrating the utility of this framework for future axion haloscope analyses.



Pros (compared to p-value): Chelsea's slide

- Most important: Logical interpretation. Bayesian approach answers the question:
  - ***How does our belief in the axion's existence change as a result of what was measured?***
  - P-value answers: ***What is the probability we would have measured something more extreme (a lower power) than we did?***
- Simplicity:
  - Very easy to combine with other experiments: just multiple prior updates in any space that overlaps
  - Nice scaling with N
  - Incorporates logarithmic priors
  - No longer need to do Monte Carlo technique
  - No need to do the truncated Gaussian for a CDF to deal with negative power fluctuations

MADMAX collaboration curious about this, maybe collaborate.

Summary

- Introduce analysis flow
- Software synthetic signal test
  → detection efficiency ~ 90 %, fudge factor for DFSZ ~ 0.8
- An improvement of background modeling is introduced
  → fudge factor for large signals ~ 1, for DFSZ ~ 0.8
  → We're working on further improving
- We're are testing bayesian analysis for ADMX

Backup

Define Rescan Region

Conditions:

- $\mathrm{SNR}_{\mathrm{DFSZ}} < 3$
- $P_{\mathrm{measured}}/P_{\mathrm{DFSZ}} + \Delta P/P_{\mathrm{DFSZ}} \times 1.281 > 0.85$
- $P_{\mathrm{measured}}/\Delta P > 3.4\sigma$