CERN

MD4147:
An update on the 50 Hz harmonics

L. Intelisano, S. Kostoglou, Y. Papaphilippou, G. Sterbini

Many thanks to all participants & contributors!

Beam-Beam & Luminosity meeting
07/06/2019

25/10/2018
Fills 7342 & 7343
MD procedure:
https://asm.cern.ch/md/requests/LHC/4147?query=\%2522Created\%2520by\%2522\%2520\%253D\%2520\%2522Sofia\%2520Kostoglou\%2522&mode=d

Motivation

1) **8 kHz cluster:** What is the origin of the 50 Hz harmonics in the 8kHz regime? Is there a similar time evolution between fundamental and high frequency components?

High sampling rate data were collected during the MD:

-**MIM**:

-B1H & B1V consecutive, fs=16*frev (T. Levens)

-**ADTObsBox**:

-bbb, every minute for Fill 7342 (single-bunch) B1 & B2 Q7, Q8, Q9, Q10 (not synchronized acquisitions), instability trigger for Fill 7343 (3x48b) B1 & B2 Q7 (D. Valuch & M. Soderen)

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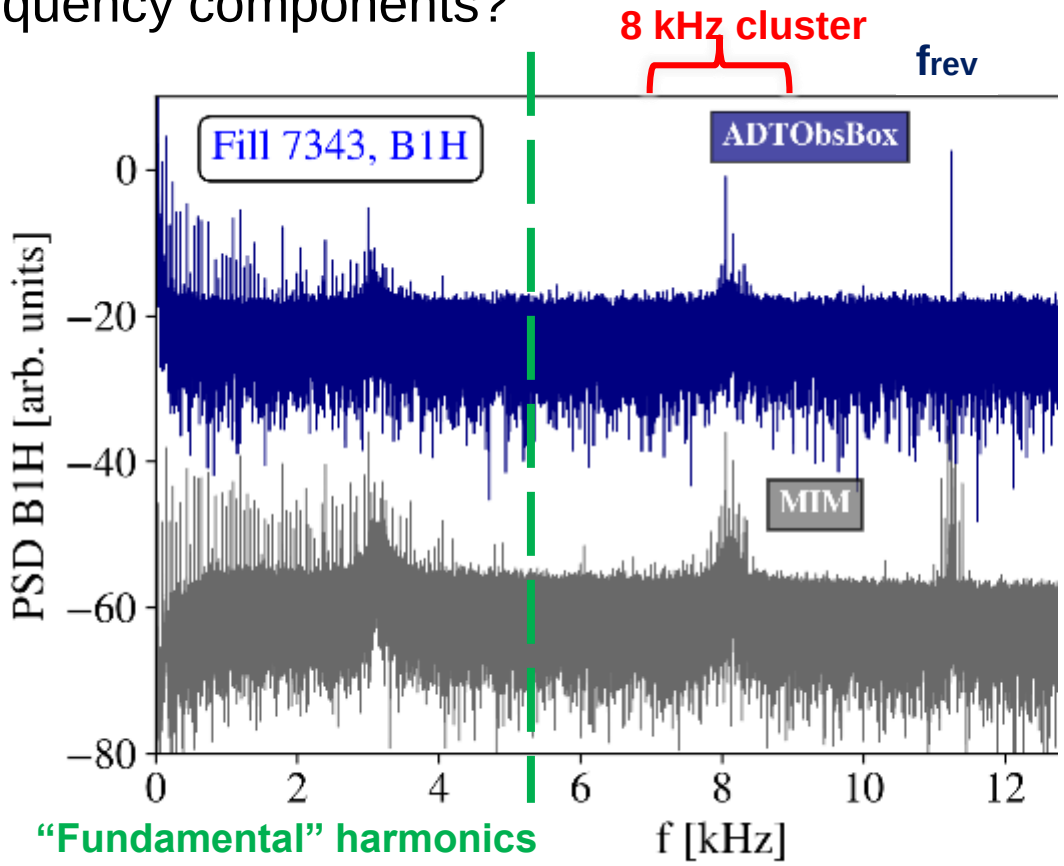

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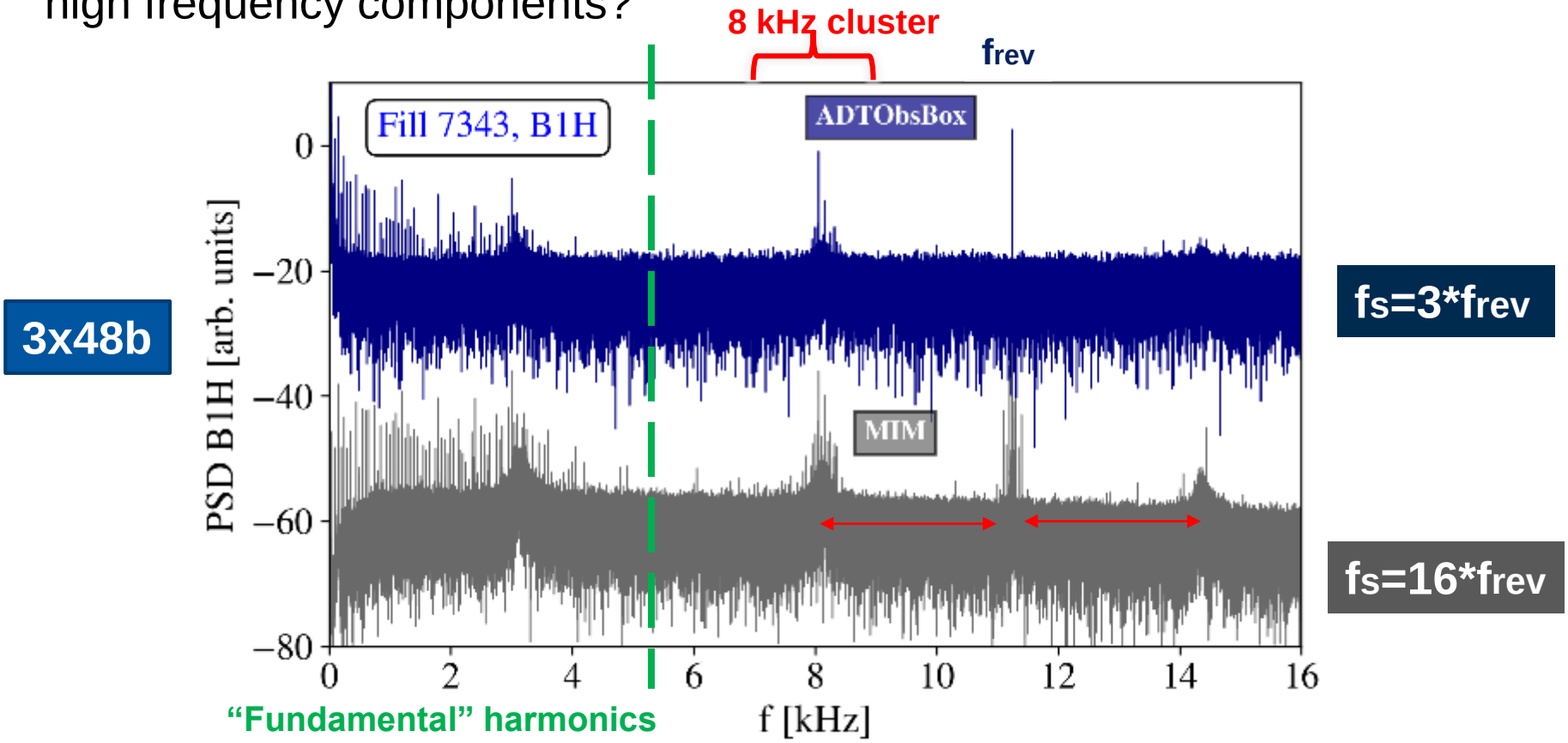

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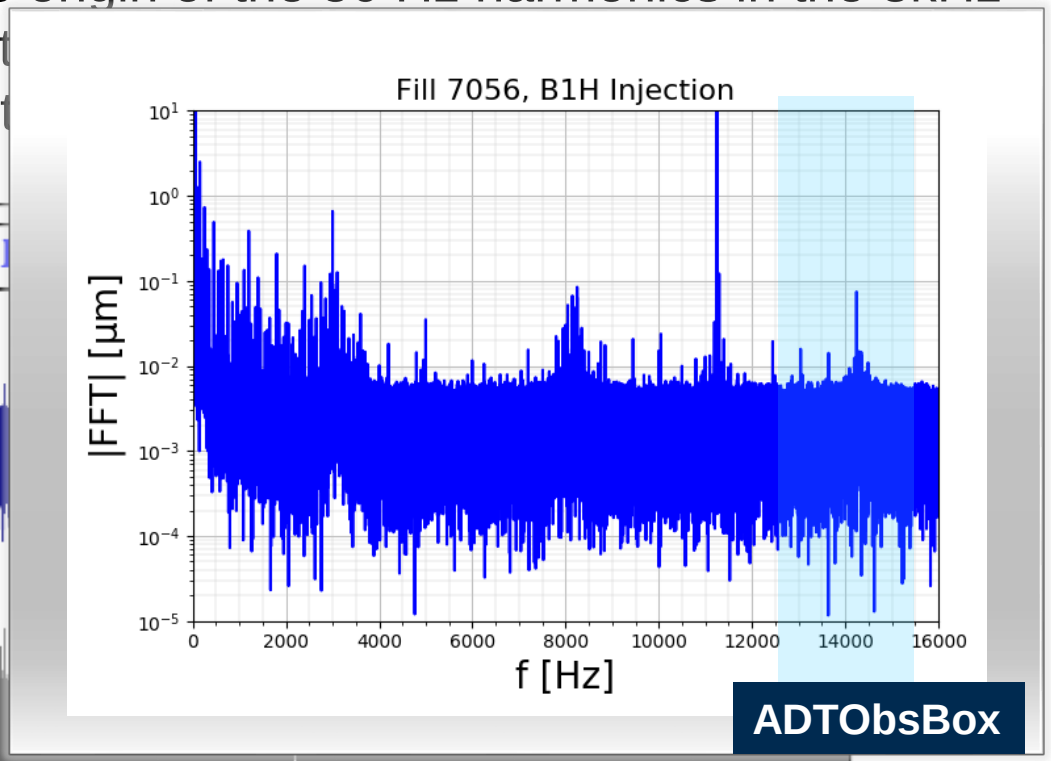
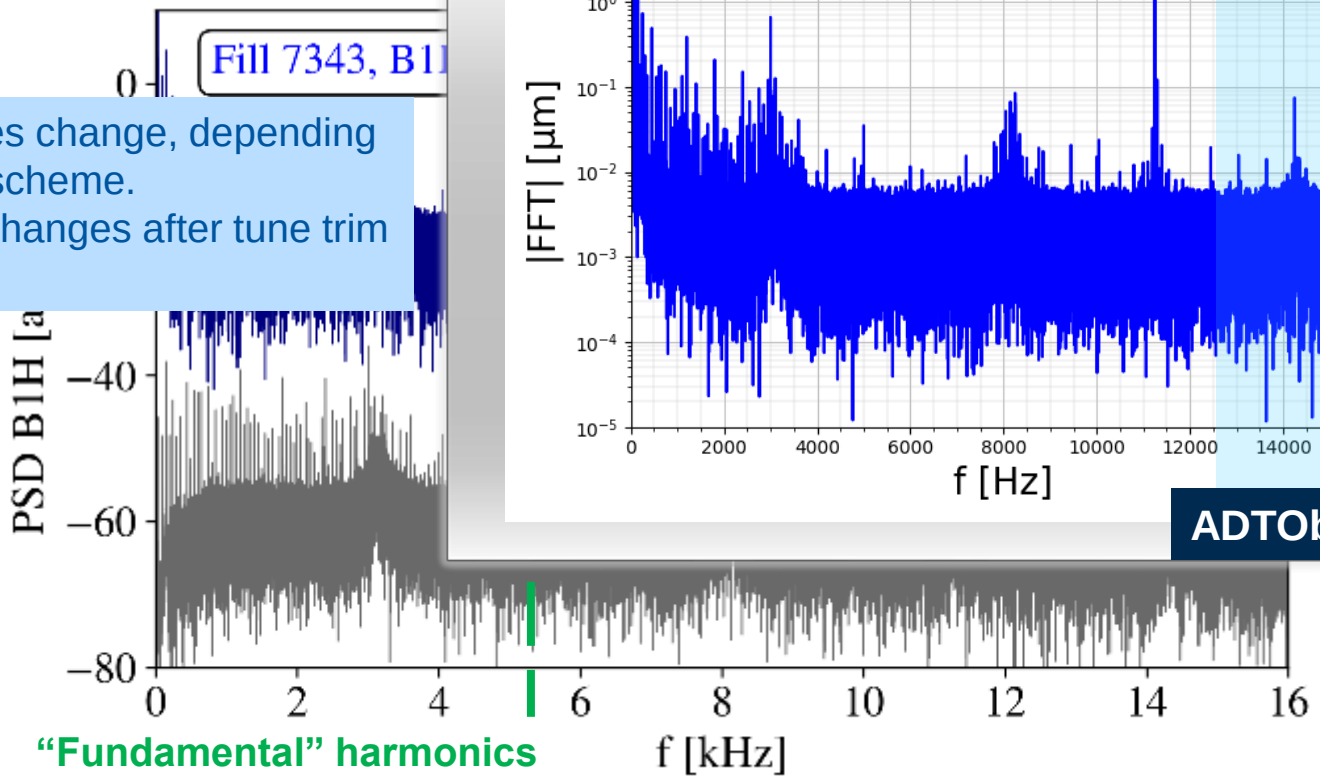
high frequency componen

- Amplitudes change, depending on filling scheme.
- Position changes after tune trim at FT.





Motivation

1) **8 kHz cluster:** What is the origin of the 50 Hz harmonics in the 8kHz regime? Is there a similar time evolution between fundamental and high frequency components?

2) **MBs Active Filters:** Which harmonics are affected? What is the complex contribution of each sector per frequency and beam at injection?

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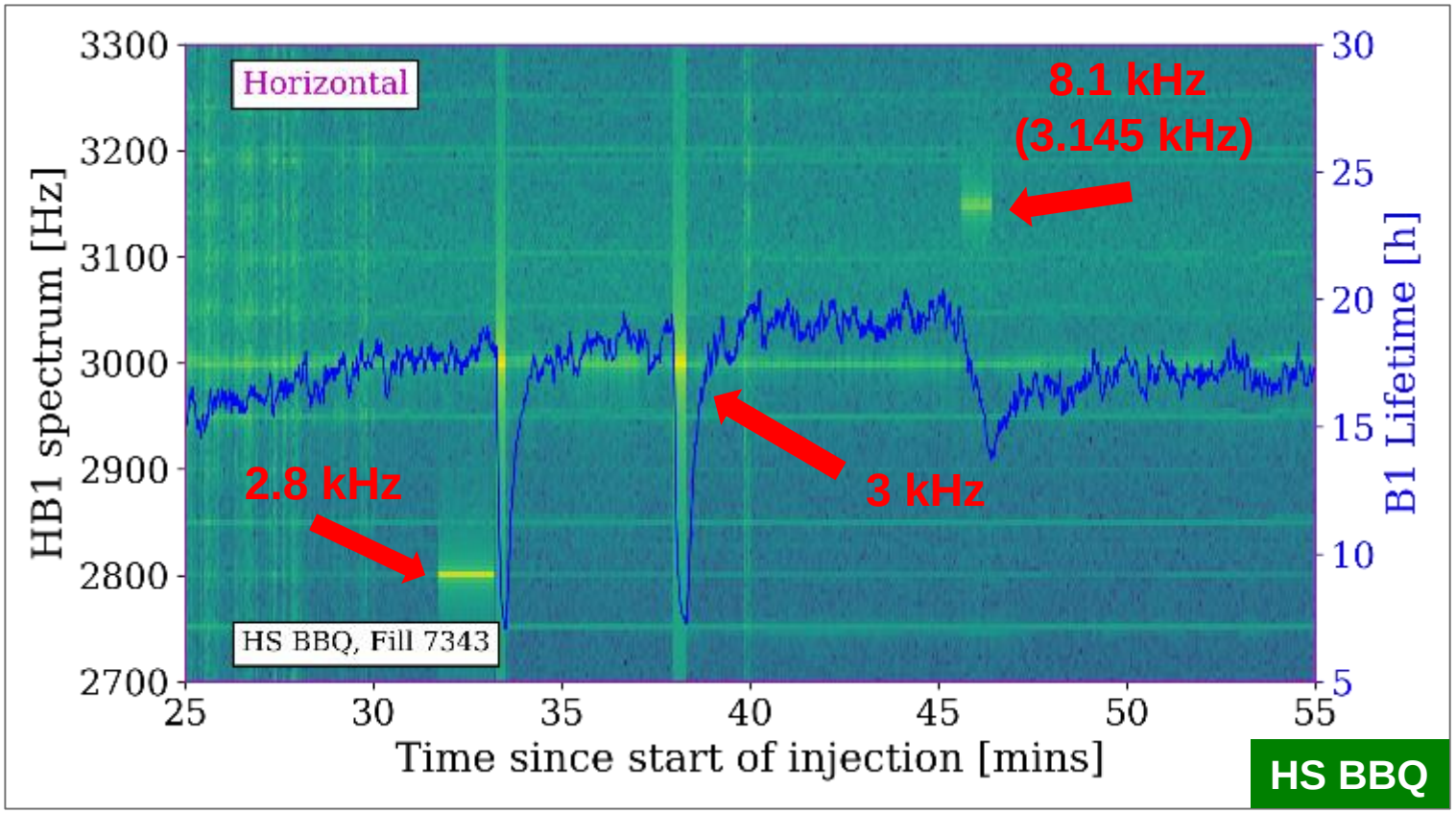
3) **ADT excitations:** Can we reproduce their impact on lifetime through simulations with injected noise?

Motivation


Horizontal
8.1 kHz
(3.145 kHz)
2.8 kHz
3 kHz
HS BBQ, Fill 7343
HB1 spectrum [Hz]
B1 Lifetime [h]
Time since start of injection [mins]
3300
3200
3100
3000
2900
2800
2700
30
25
20
15
10
5
25
30
35
40
45
50
55
HS BBQ

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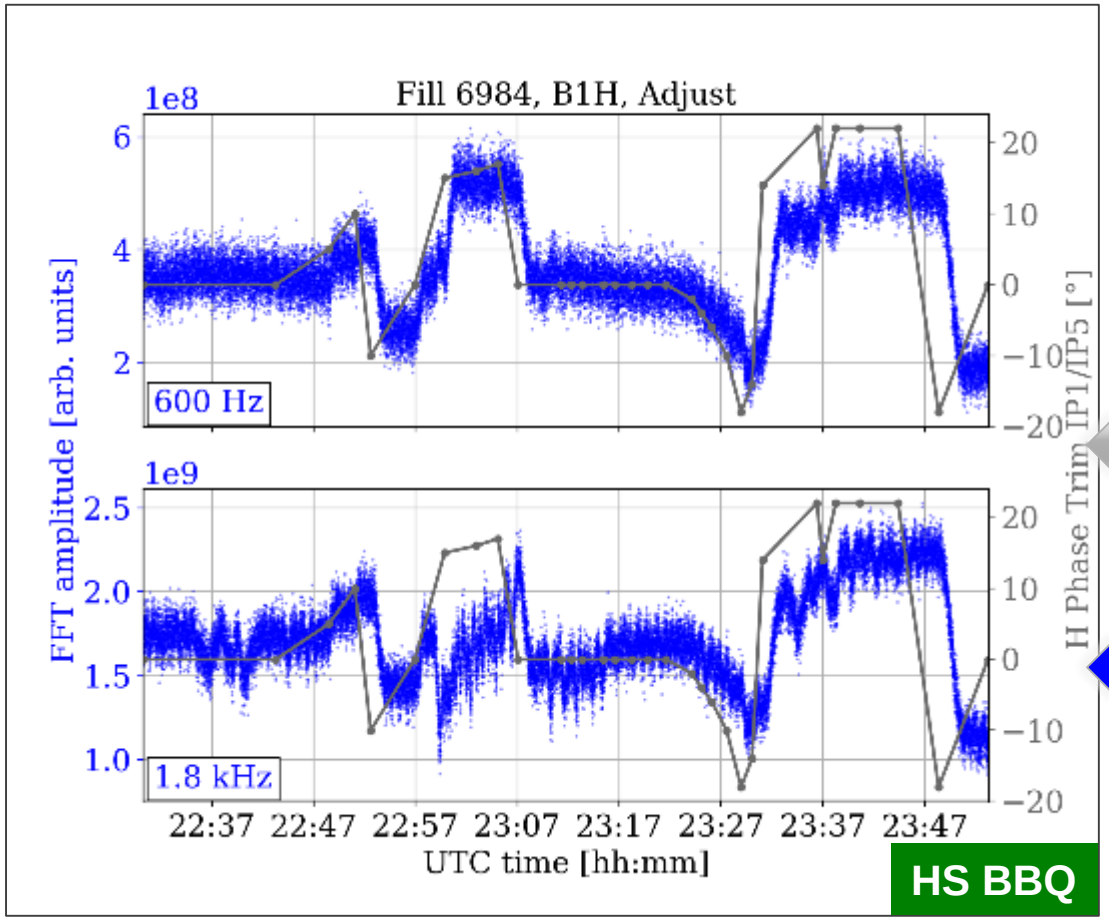
4) **IP1/ phase scan:** Can we extract information on the source from the changes in the evolution of the harmonics observed at top energy?

Motivation

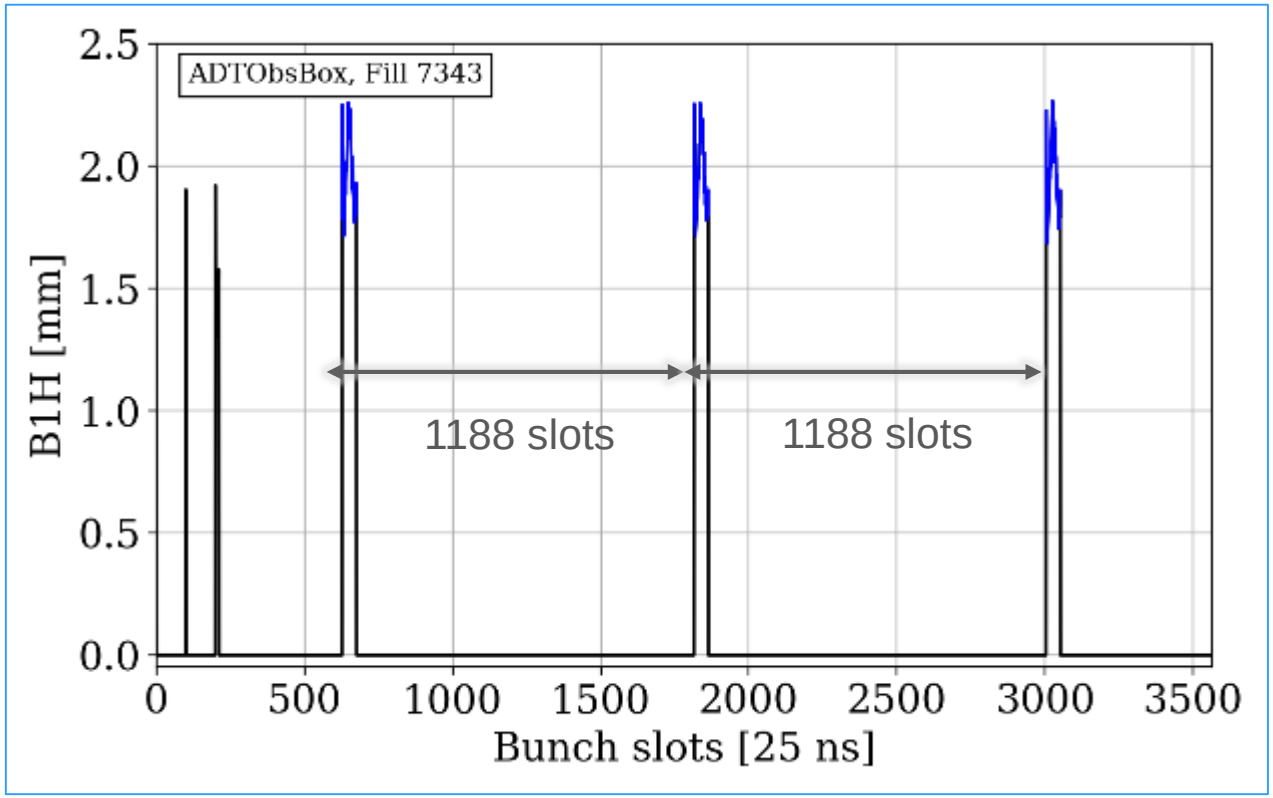


Phase trim SET, not current

Beam response at 0.6, 1.8 kHz

MD overview

- MD#4 25/10/2018, 5 h slot at injection. Due to B2 RF problem, **only 2.5 h for the tests**.
- Two fills:
  - **I.** **Fill 7342:** Single bunch to test the ADT excitations and interlock on quadrupole PC for the IP1/5 trim.
  - **II.** **Fill 7343:** 3x48b symmetrically placed **with a 120 degrees azimuthal phase** (constant sampling for the ADTObsBox).



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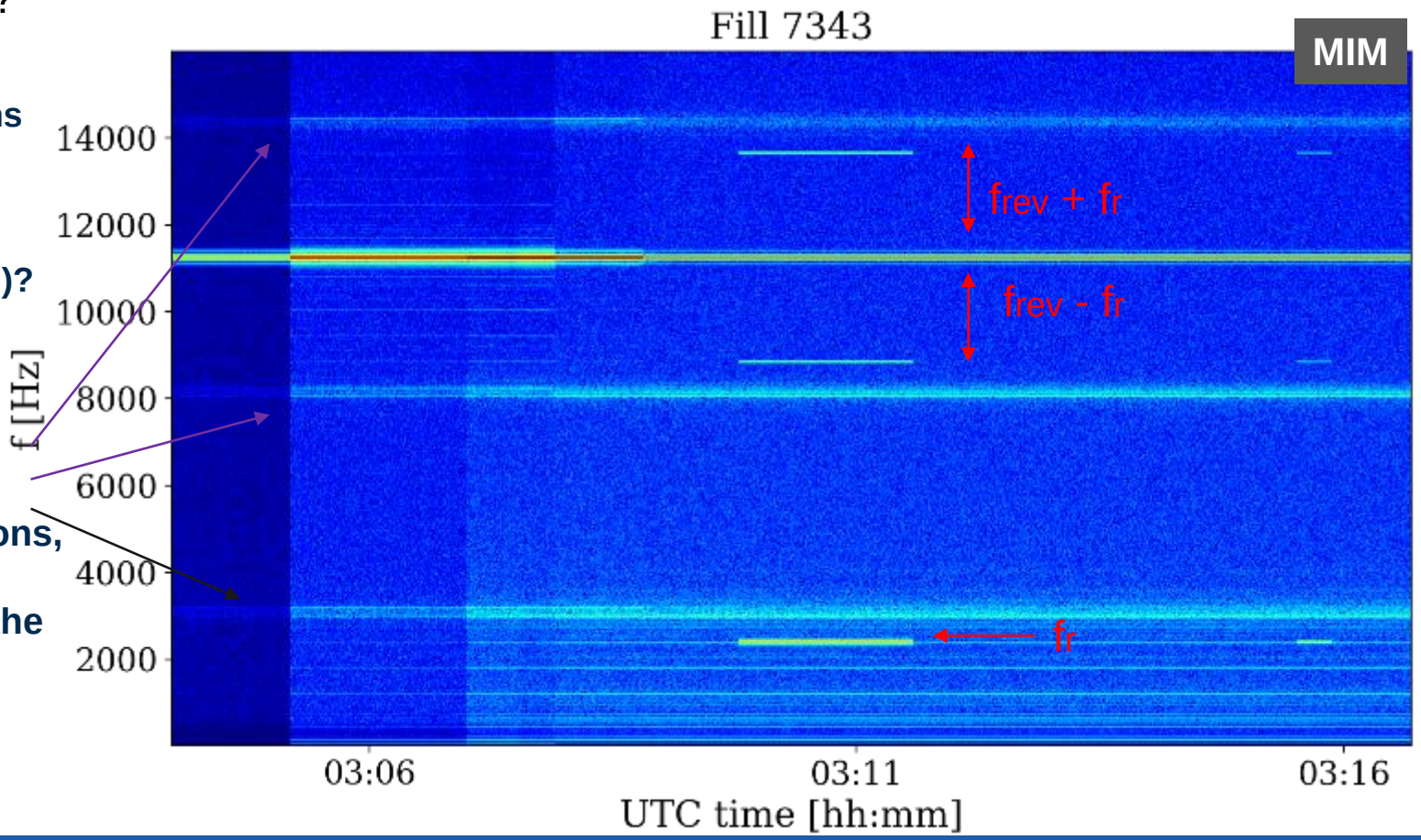
- *Steps Fill 7342:*
  - ADT excitations: B1H 0.6, 2.5 and 2.4 kHz. B1V, B2H, B2V individually 2.4 kHz.
  - IP1/5 phase scan: Trim of +20 degrees to B1H, beam was dumped due to interlock.
- *Steps Fill 7343*
  - ADT excitations: B1H 2.4, 2.8, 3, 7.6, 8.8, 8.1 kHz. B2H 3 kHz.
  - Active filters: Disabled one-by-one. Disabled all of them as a last step.
  - IP1/5 phase scan: B1H. B1V, B2H, B2V ±8 degrees.

8 kHz cluster

- How it started: During an ADT excitation f_r=3 kHz, sidebands ($f_{rev} \pm f_r$) are visible.
- If every dipolar excitation leads to sidebands around the revolution frequency, then is the 8 kHz cluster the sideband of the 50 Hz harmonics in the 3 kHz regime?

Real excitations or due to sampling (dephasing between trains)?

If real excitations, are these sidebands of the 3 kHz?

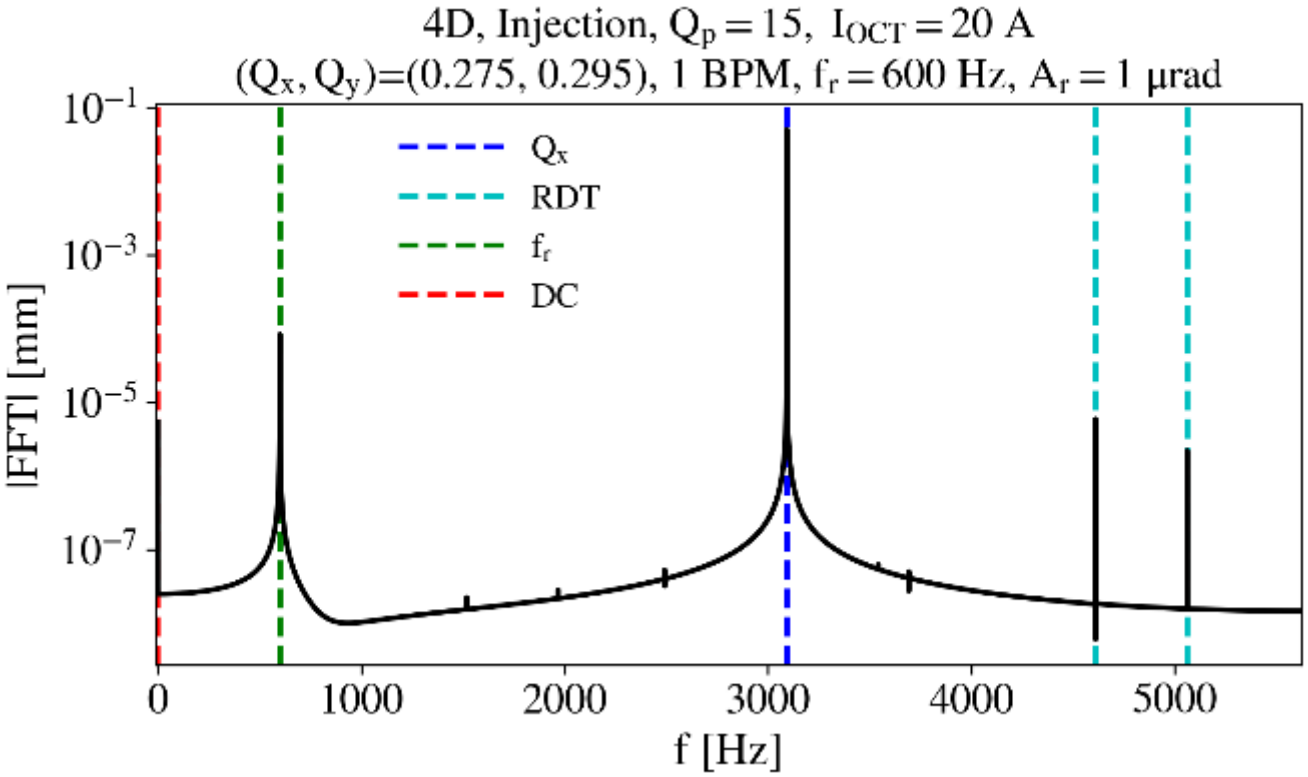


8 kHz cluster

Possible explanation 1: They are sidebands

- In order to understand if the sidebands are a real excitation or the result of errors in the sampling → simple example

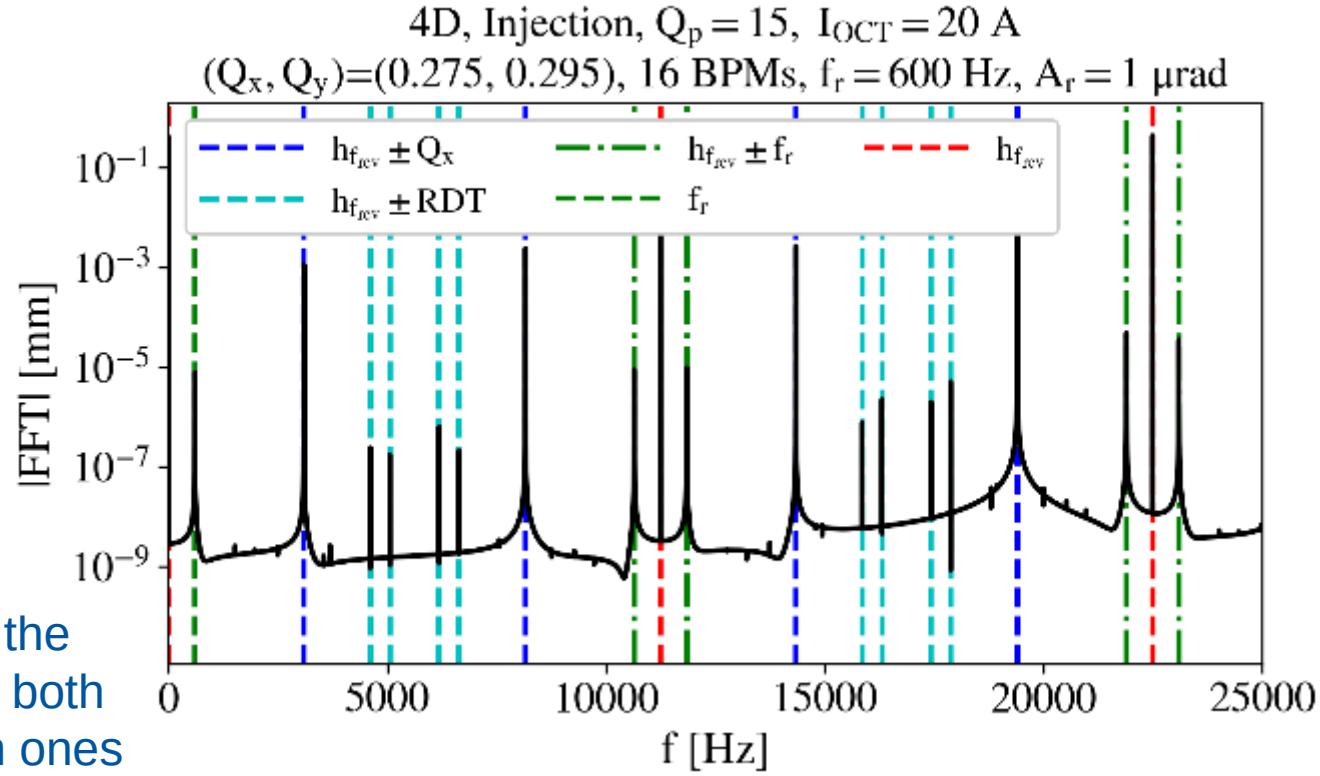
SixTrack, 1 particle at 0.1 σ & 45 degrees, injection, 4D, excitation at 600 Hz, **1 (virtual) BPM**



8 kHz cluster

- Simple example: 16 virtual BPMs placed in (approximately) equal phase advances.

SixTrack, 1 particle at 0.1 σ & 45 degrees, injection, 4D, excitation at 600 Hz, **16 (virtual) BPMs**

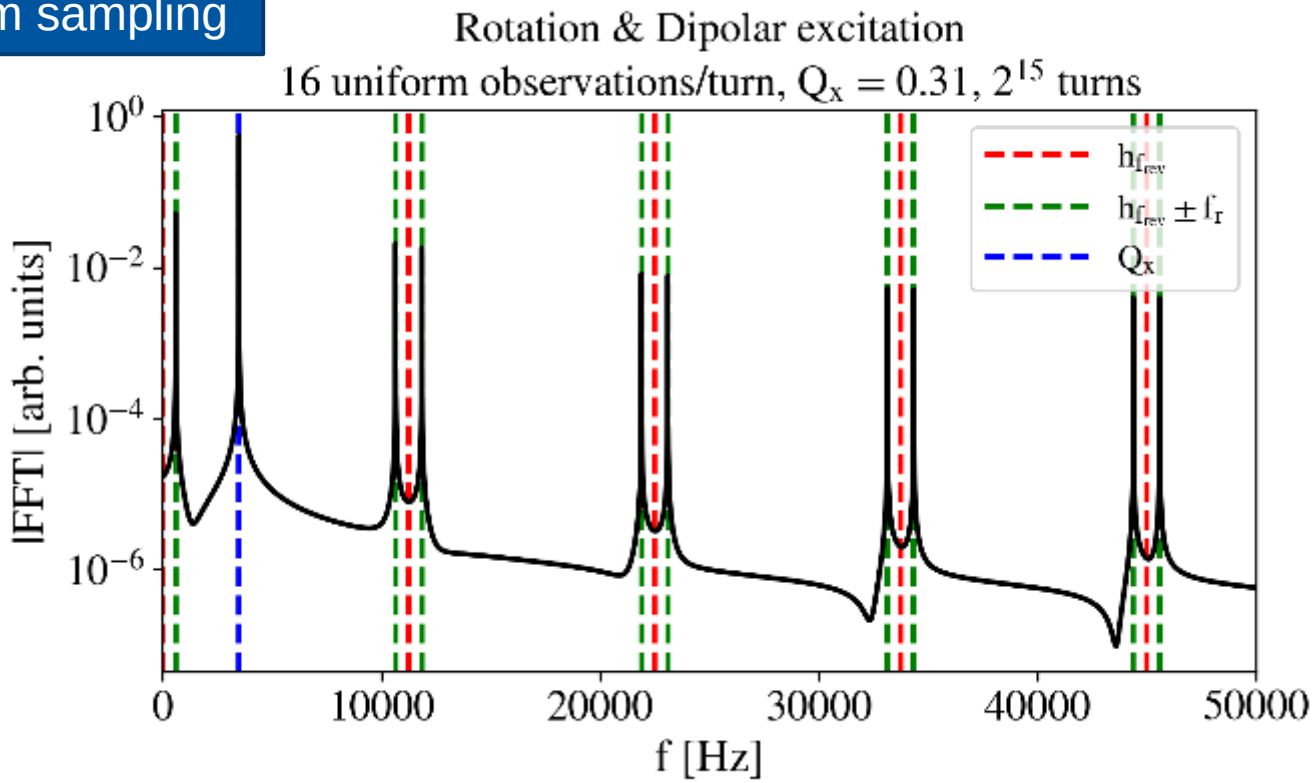


Sidebands around the revolution frequency both from f_r and Q_x. Which ones are due to sampling error and which ones are real?

8 kHz cluster

- Even simpler example→ Rotation & Dipolar excitation

Uniform sampling

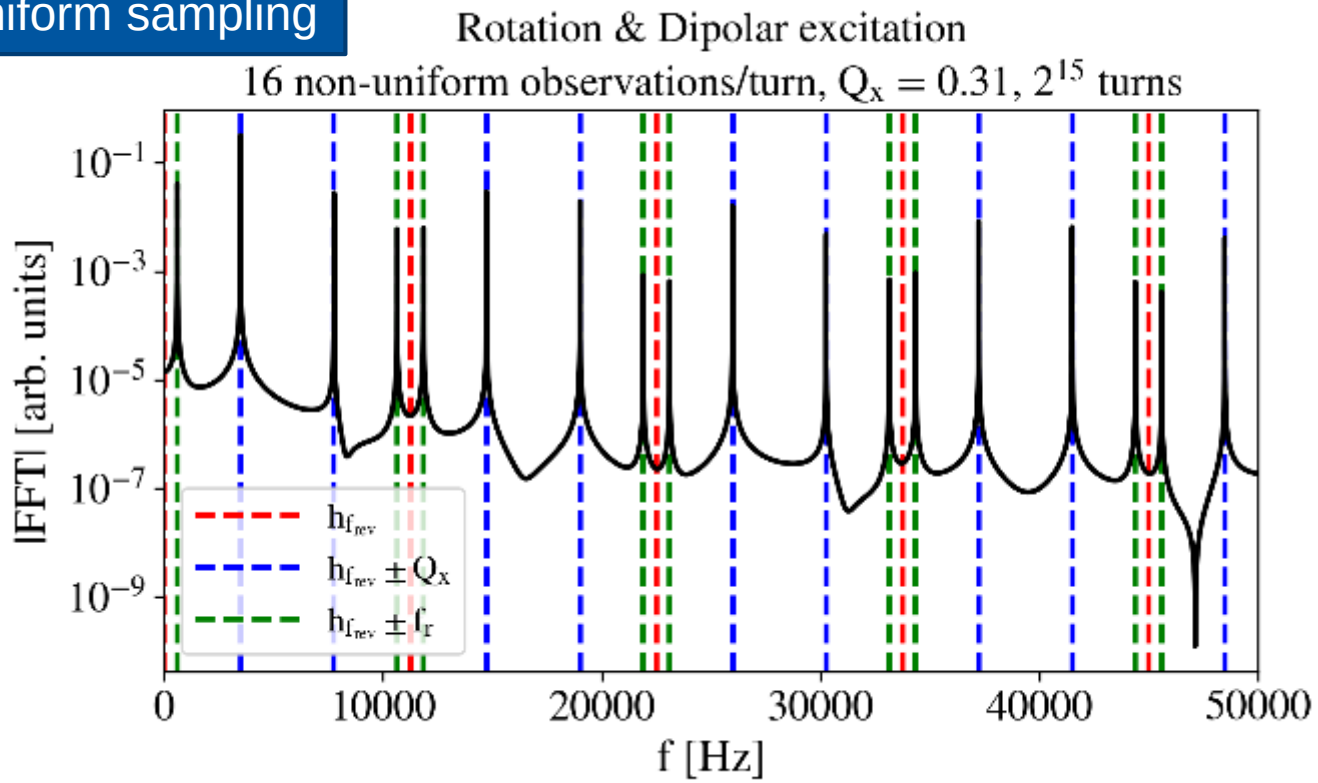


Sidebands of the noise

8 kHz cluster

- Even simpler example→ Rotation & Dipolar excitation

Non-uniform sampling



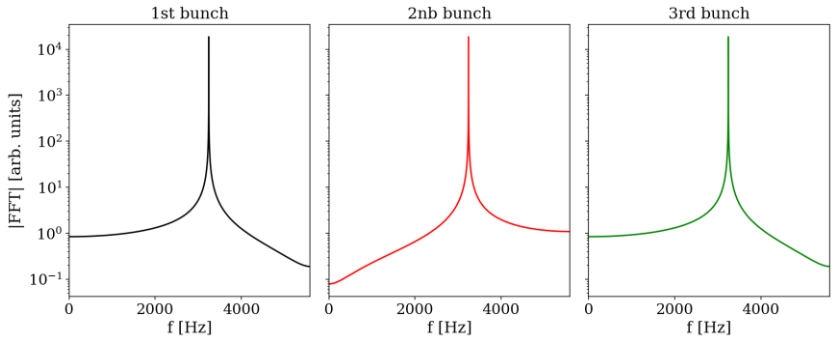
Sidebands of the noise & Q_x

8 kHz cluster

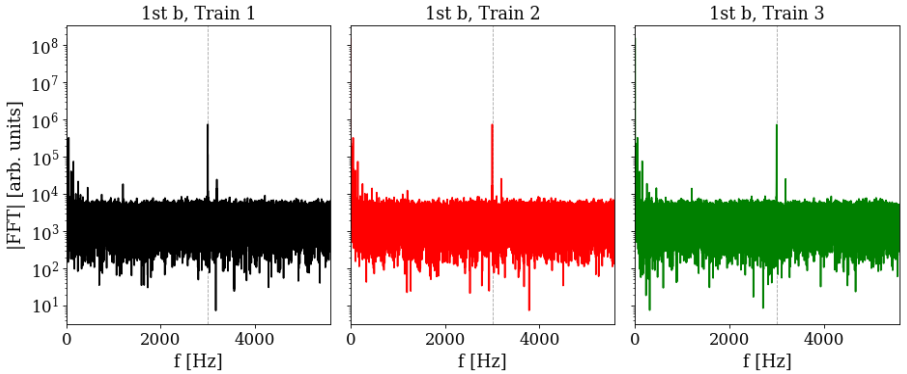
VERY PRELIMINARY

Possible explanation 2: A sampling error

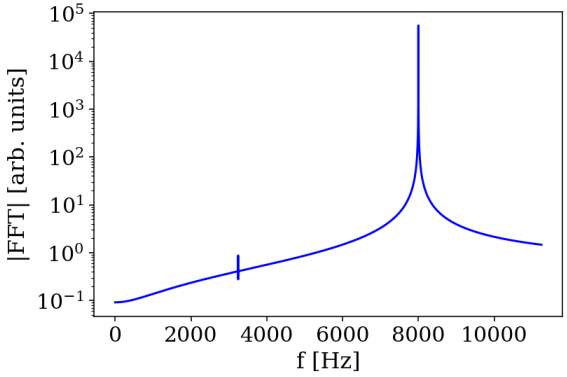
Simple example of 3 bunches with a time delay → 8 kHz excitation



Fill 7342 during ADT excitation

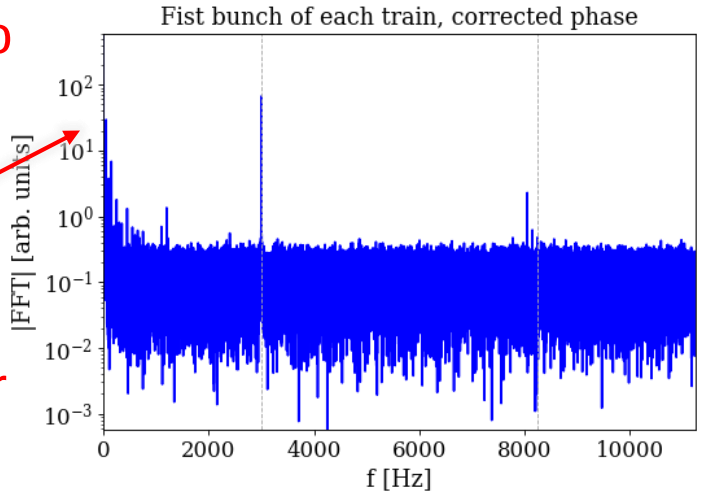


Correction of phase in frequency domain and sum of the 3 spectra



Excitation but no sideband, once dephasing is corrected!

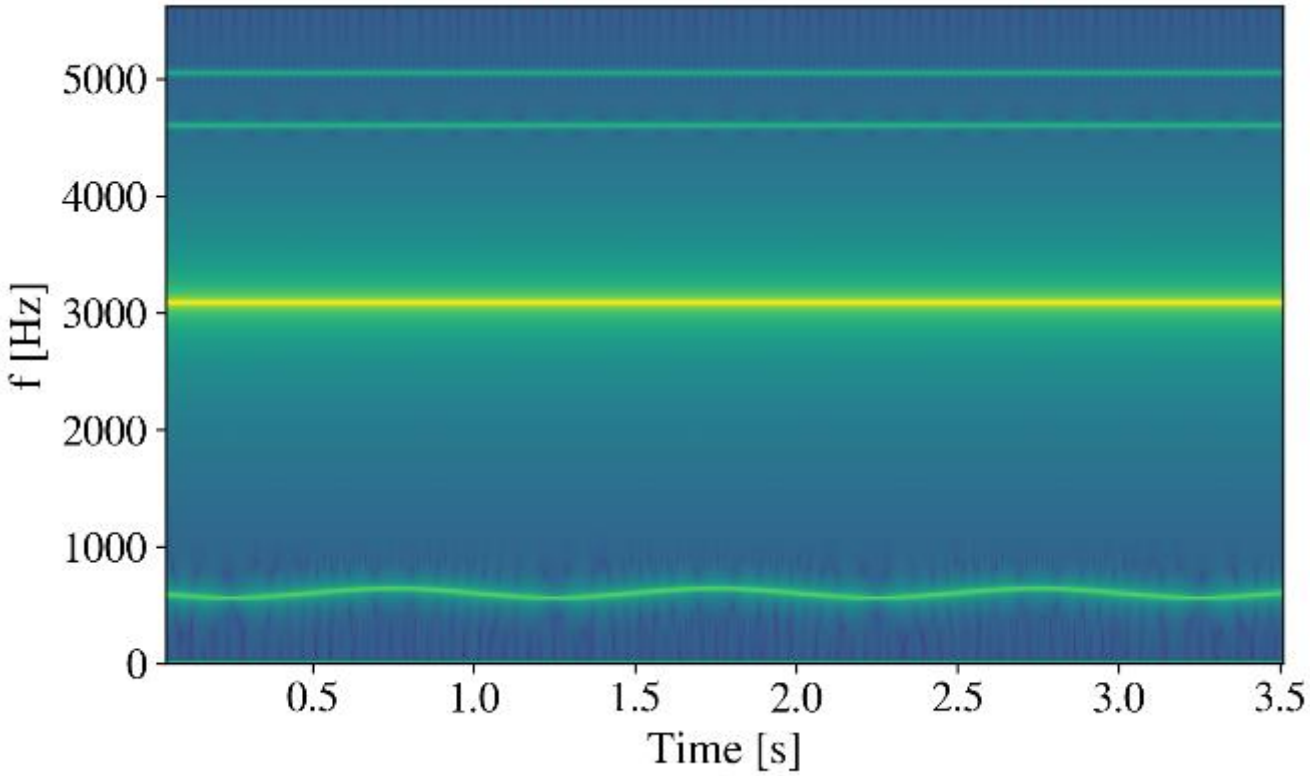
Fill with trains under investigation..



8 kHz cluster

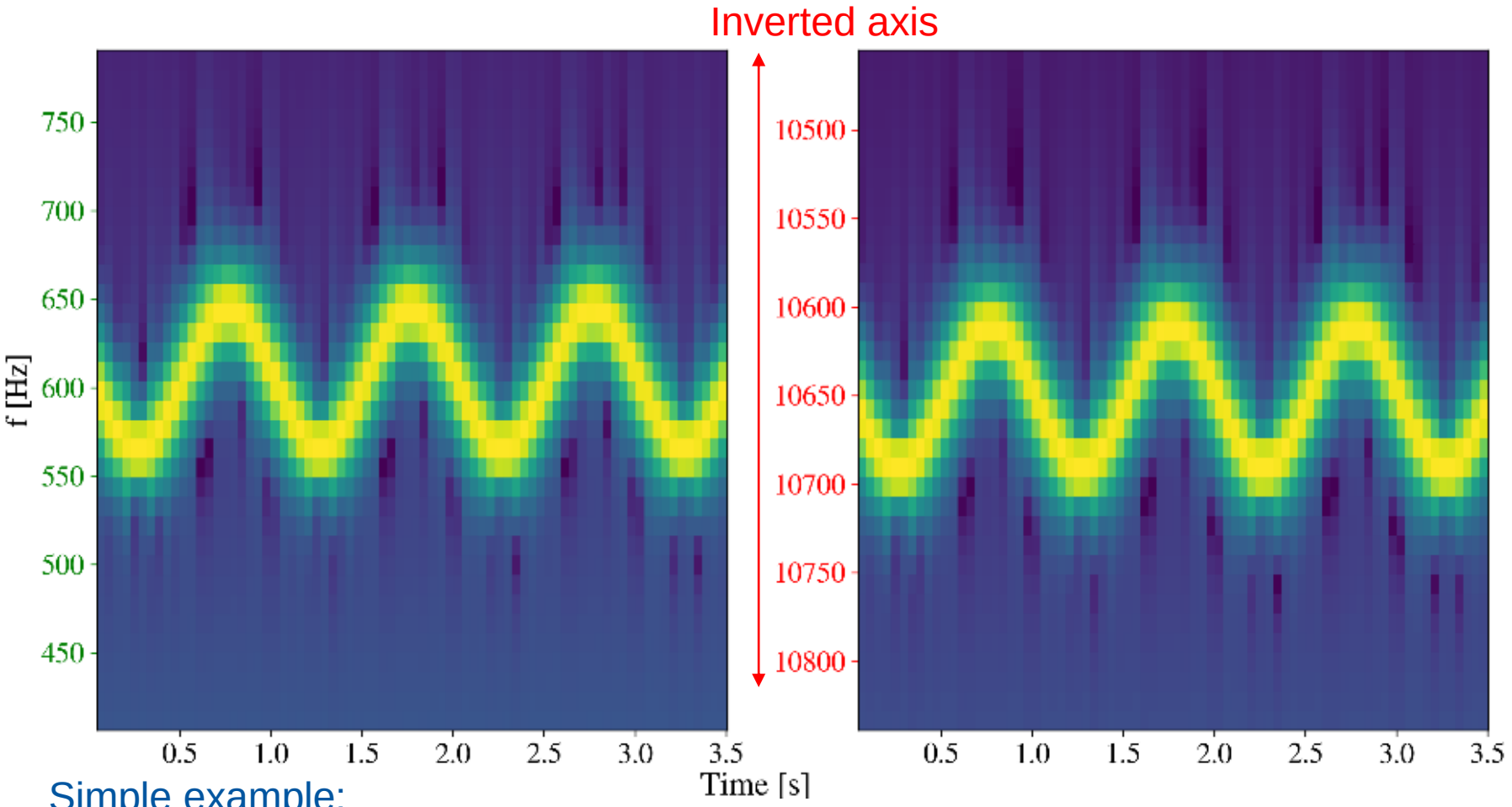
- Simple SixTrack model **vs Fill 7342 (single bunch)**
  1. **Frequency modulation:** The harmonics are modulated with the mains of the electrical network.

Simple example:
FM dipolar excitation



8 kHz cluster

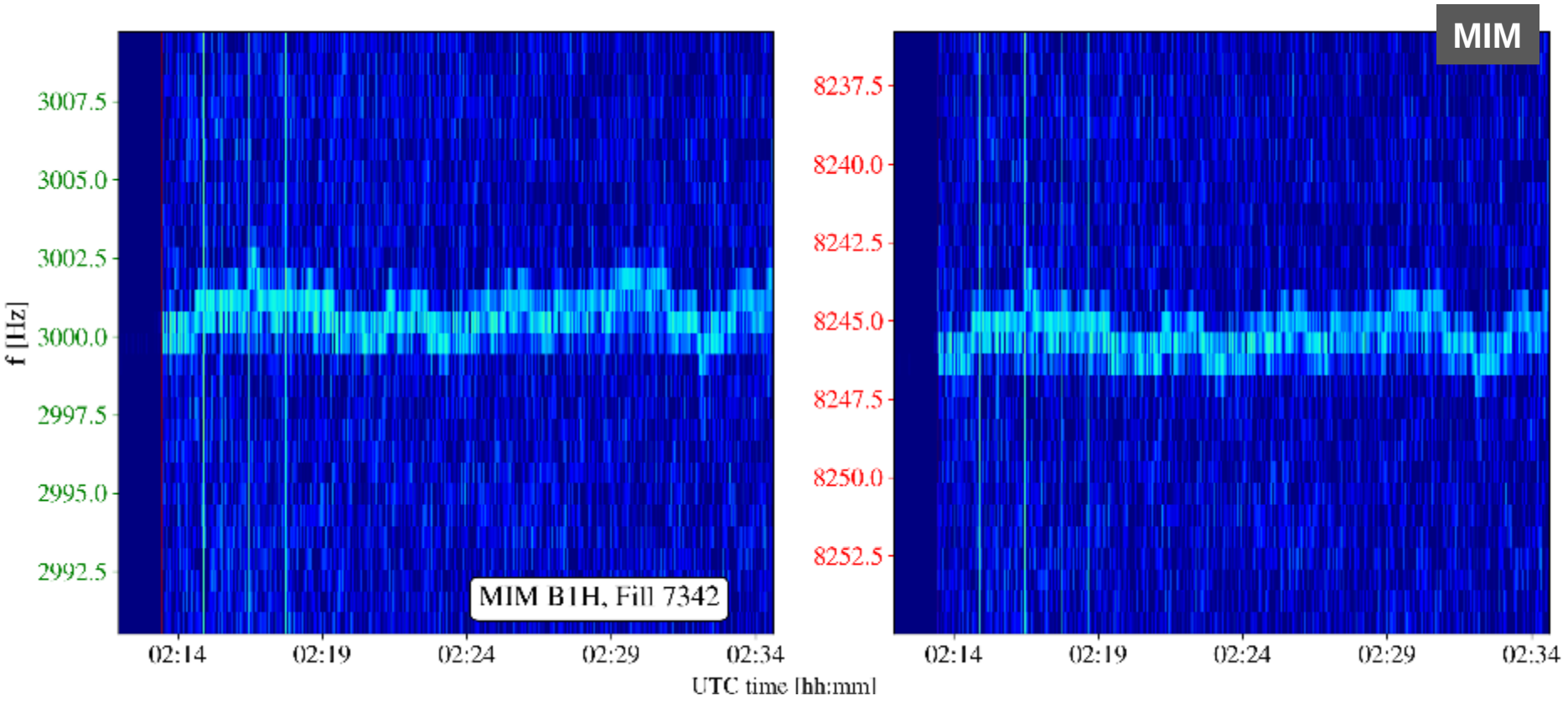
1. Frequency modulation: Sideband modulated with opposite phase



Simple example:
FM dipolar excitation

8 kHz cluster

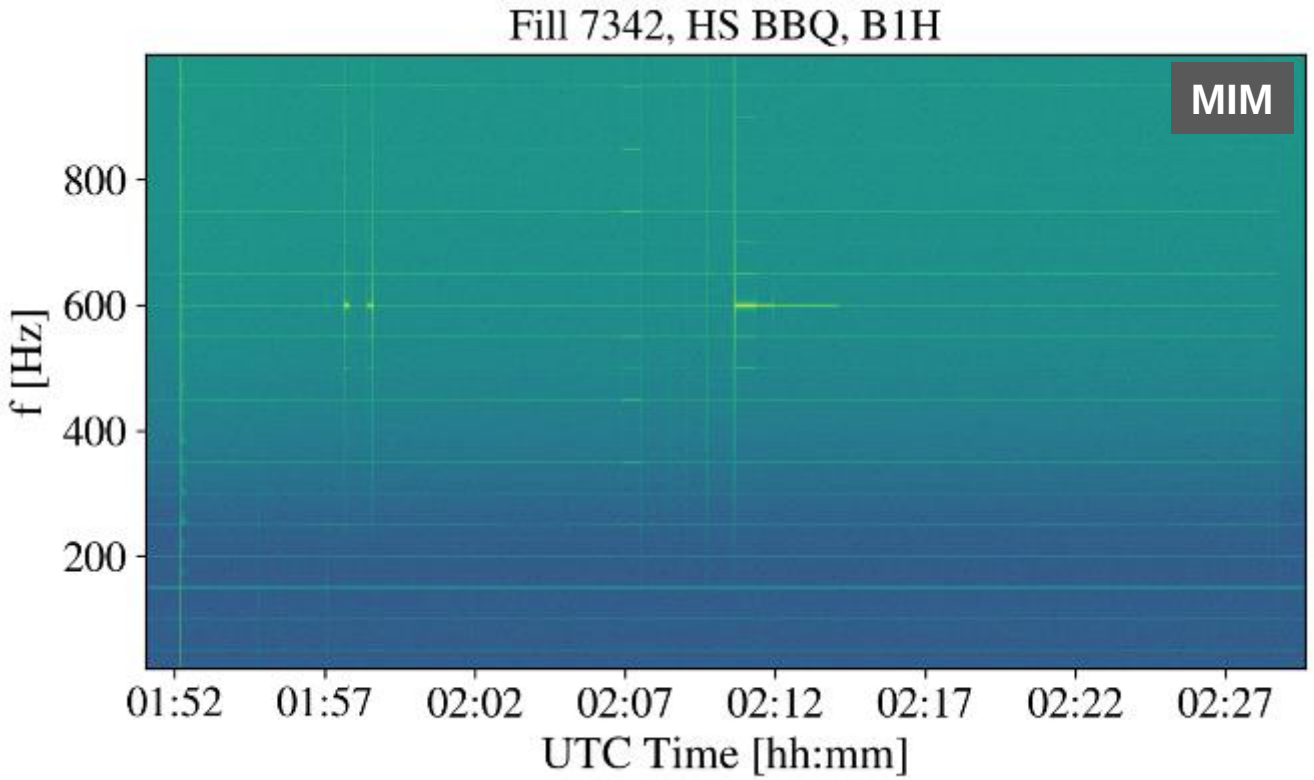
1. **Frequency modulation: Sideband modulated with opposite phase ✓**



Fill 7342 (single bunch)

8 kHz cluster

Note: The 50 Hz harmonics are visible even with a single bunch. No need for trains, contrary to what was discussed in the past.

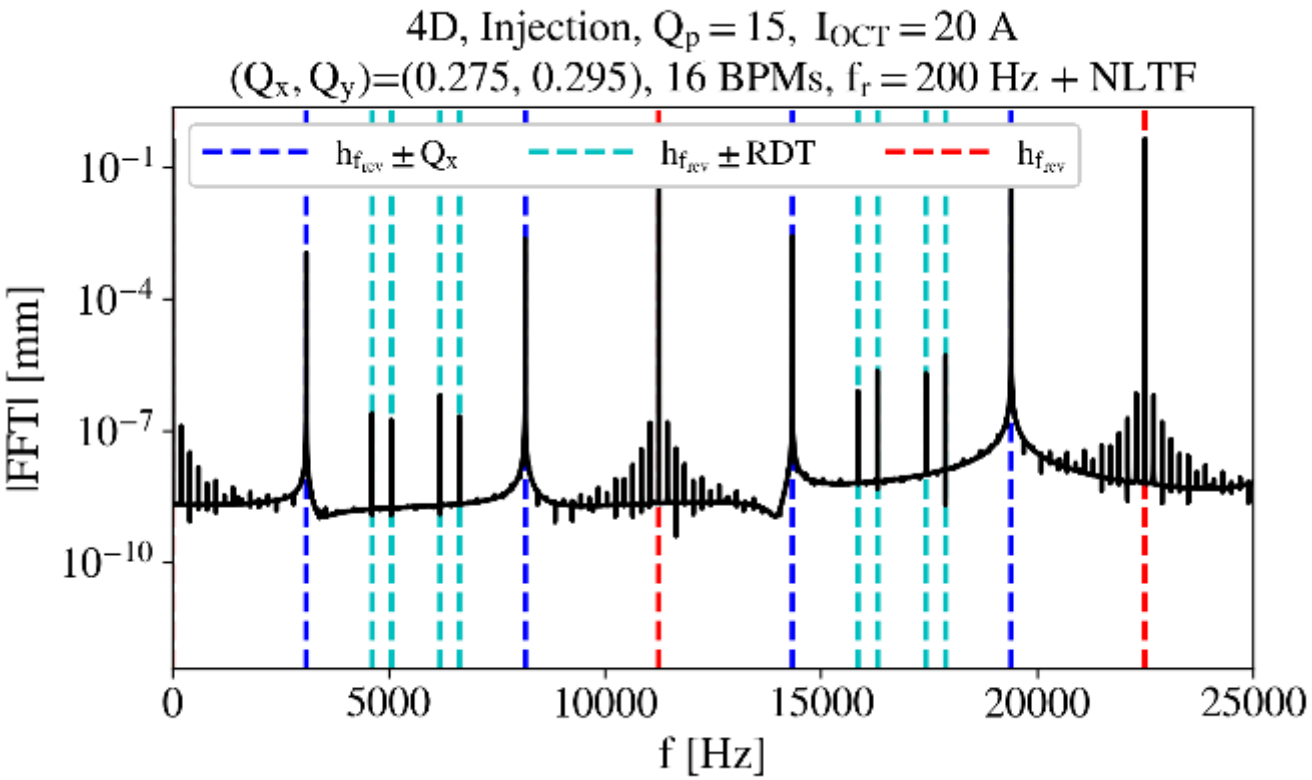


Fill 7342 (single bunch)

8 kHz cluster

2. Amplitude: Main excitations and sidebands should be symmetric

NLTF to produce harmonics



Simple example:
Dipolar excitation & Non linear transfer function

8 kHz cluster

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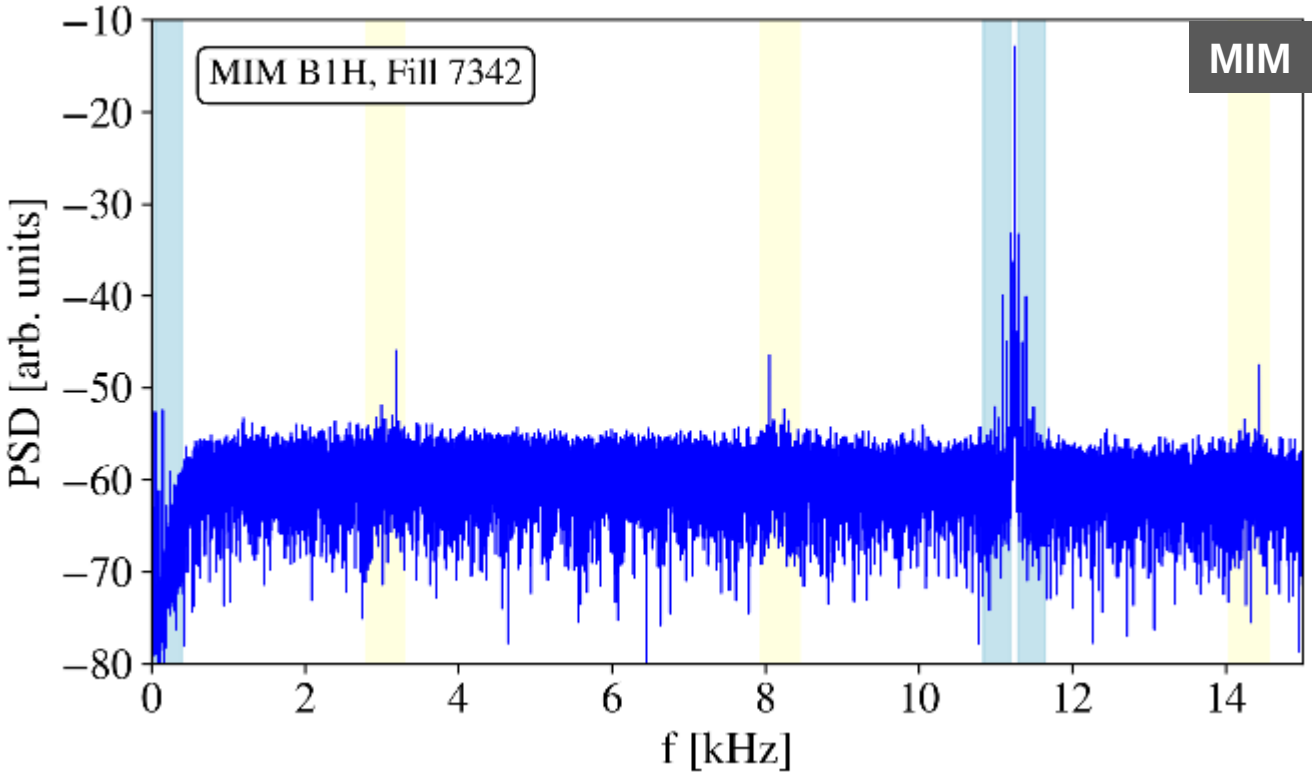
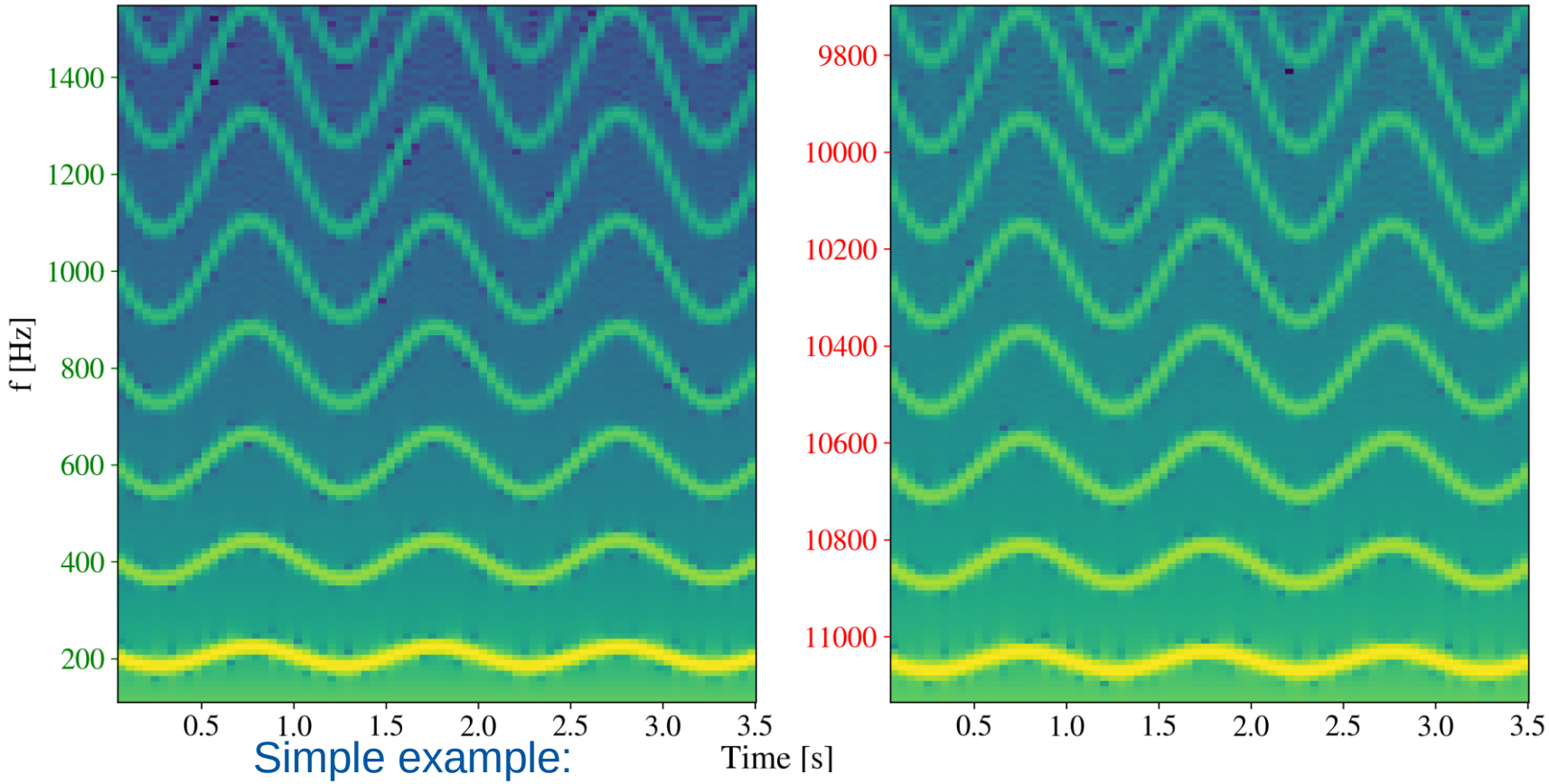


Fill 7342 (single bunch)

8 kHz cluster

Note: When harmonics of the same source are present, the amplitude of the frequency modulation will scale with the order of the harmonic (which is indeed what has been observed in the past).

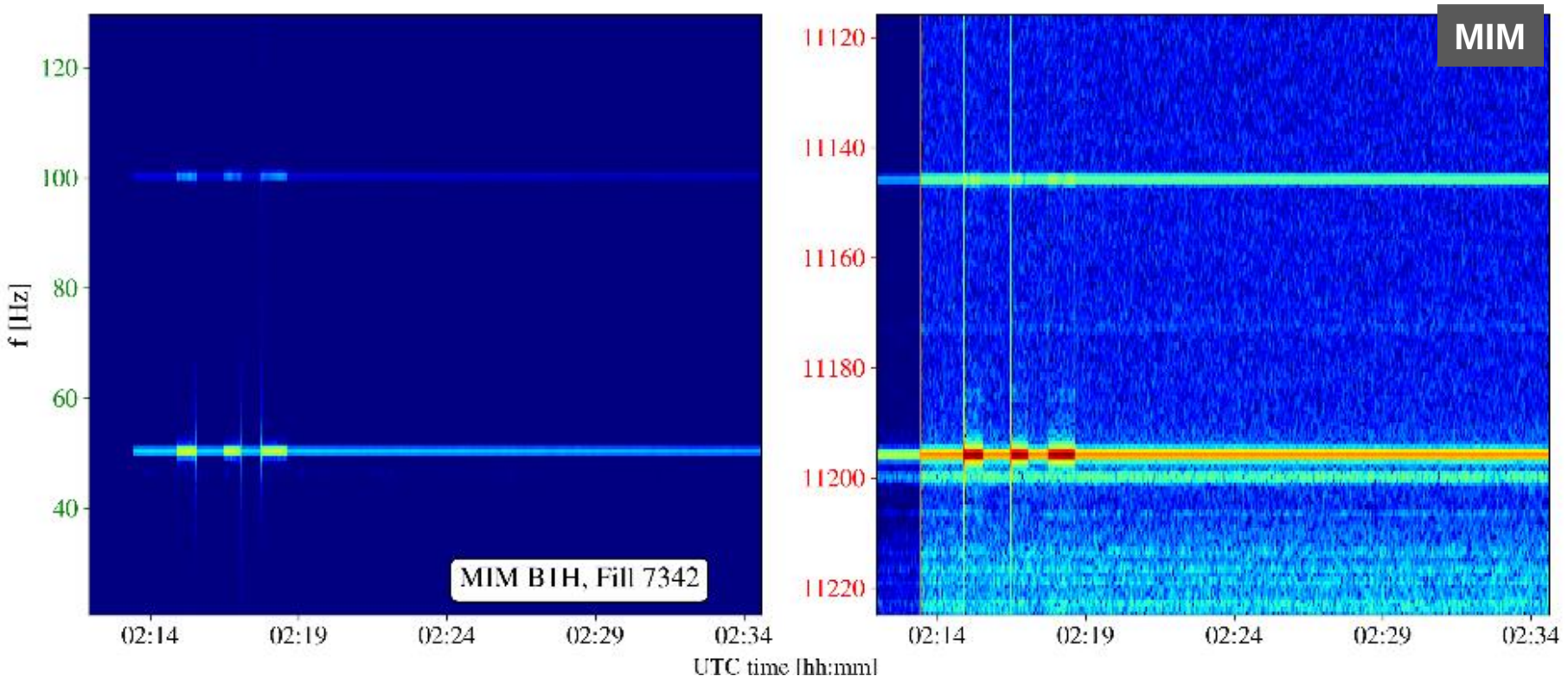


Simple example:

Dipolar excitation & Non linear transfer function & FM

8 kHz cluster

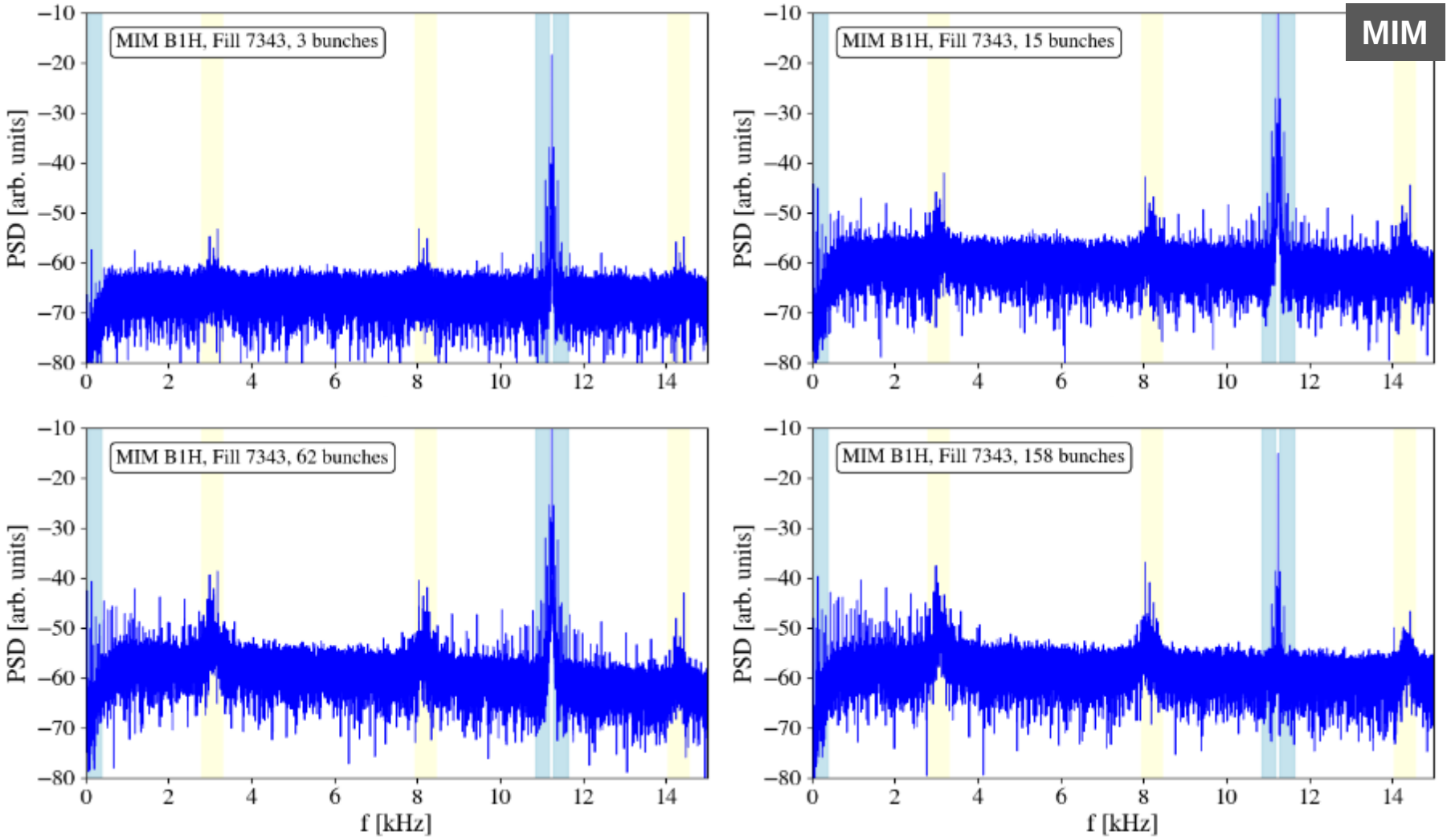
3. **Excitation: The excitations applied in the main frequency should be visible in the sideband. ✓**



Fill 7342 (single bunch)

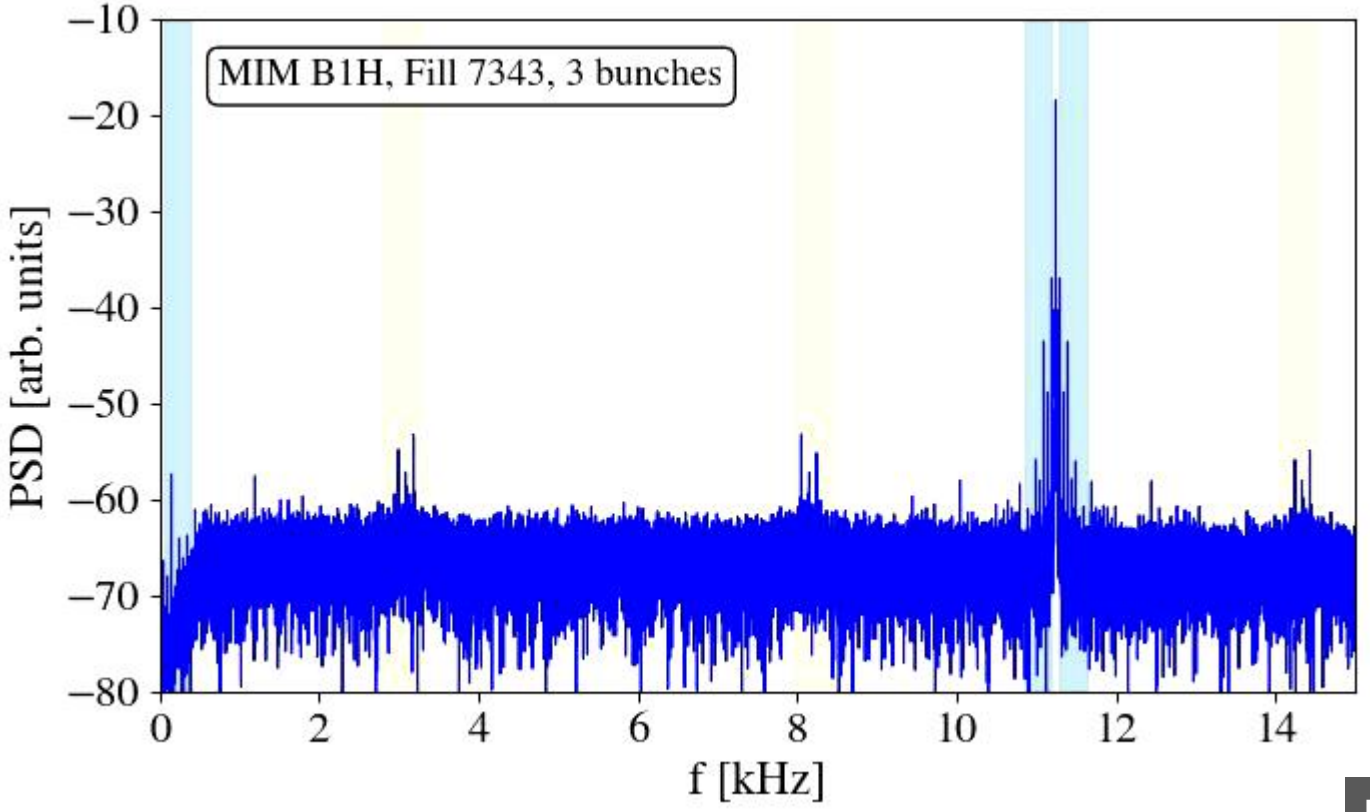
8 kHz cluster

- When the “sideband” hypothesis and the observations do not agree:
  Fill 7343 (trains)



8 kHz cluster

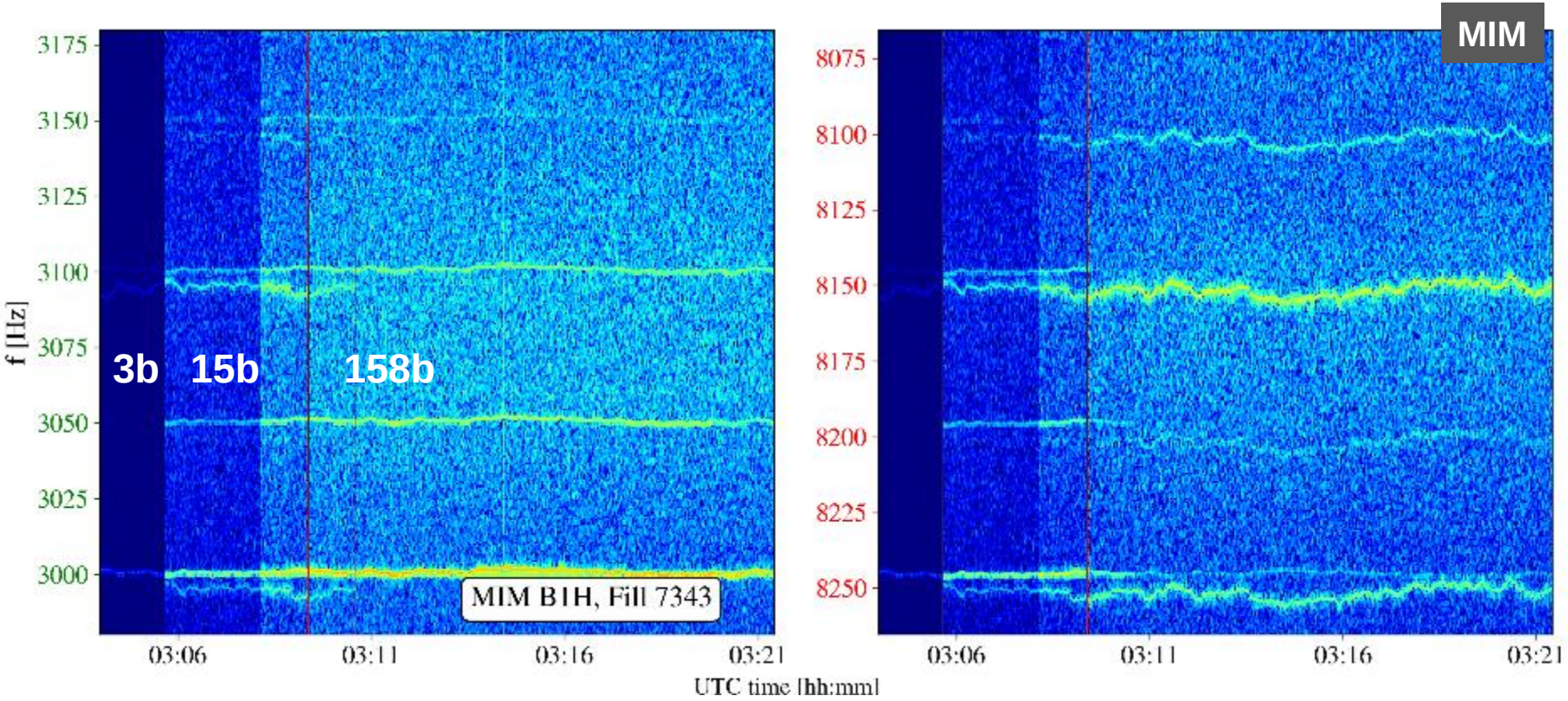
Video!



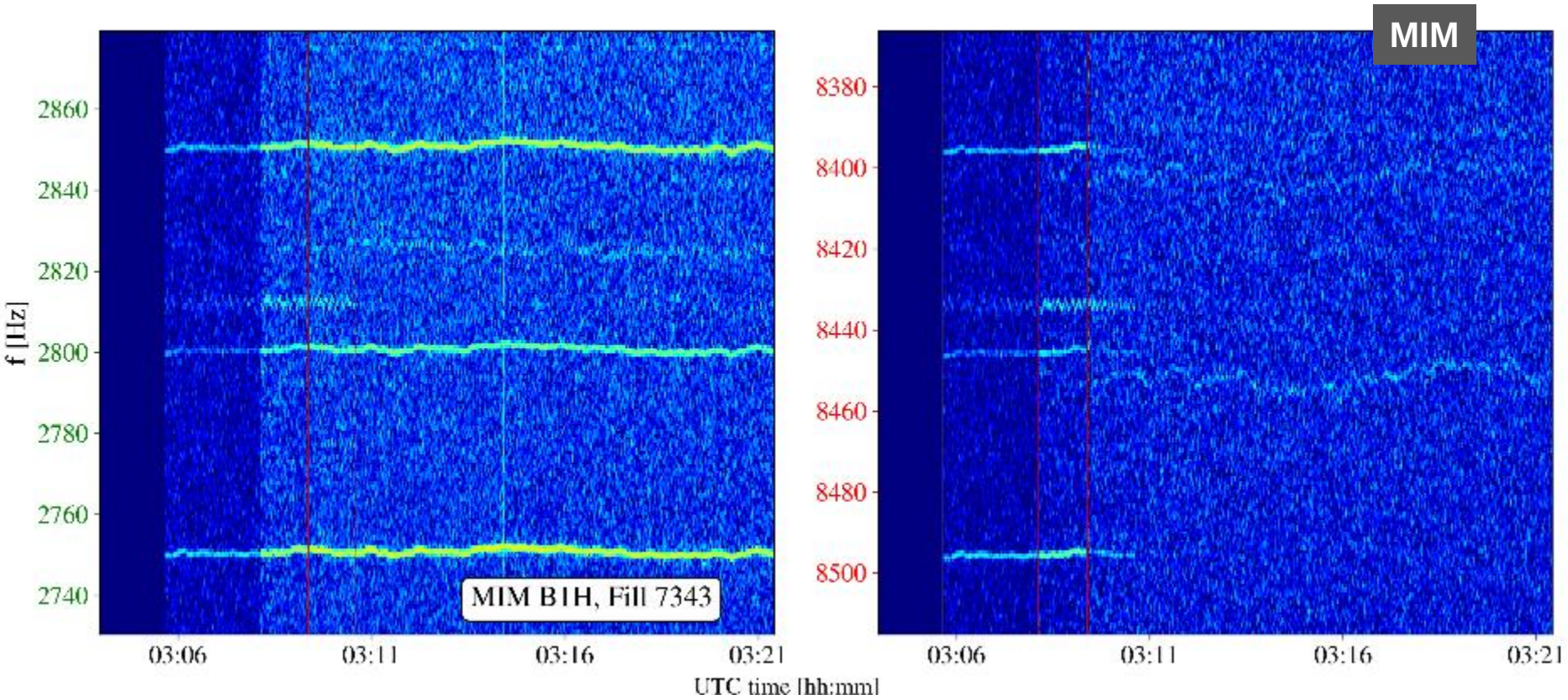
MIM

The position of the clusters does not seem to change, only the amplitudes become asymmetric. Possible reason: Sampling? Need to correct for the dephasing between trains?

8 kHz cluster



8 kHz cluster



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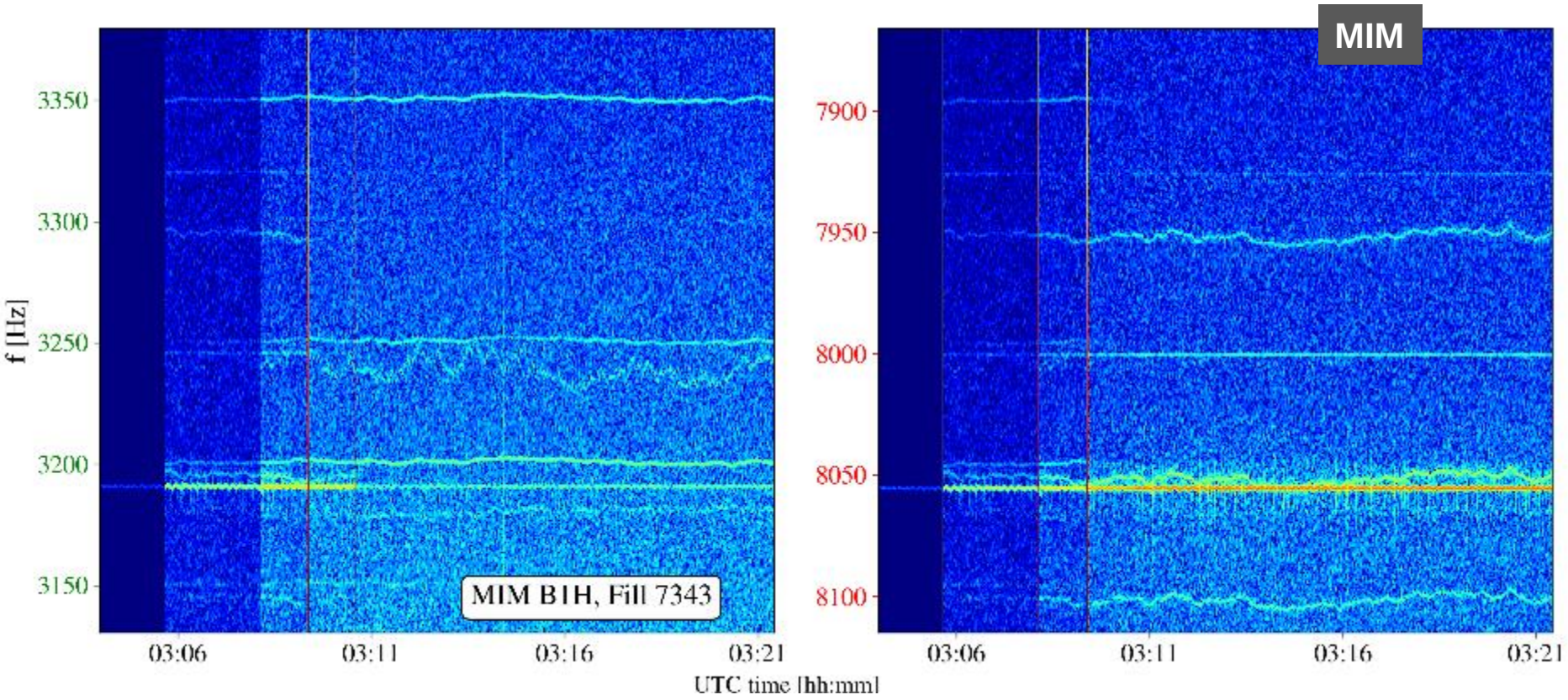
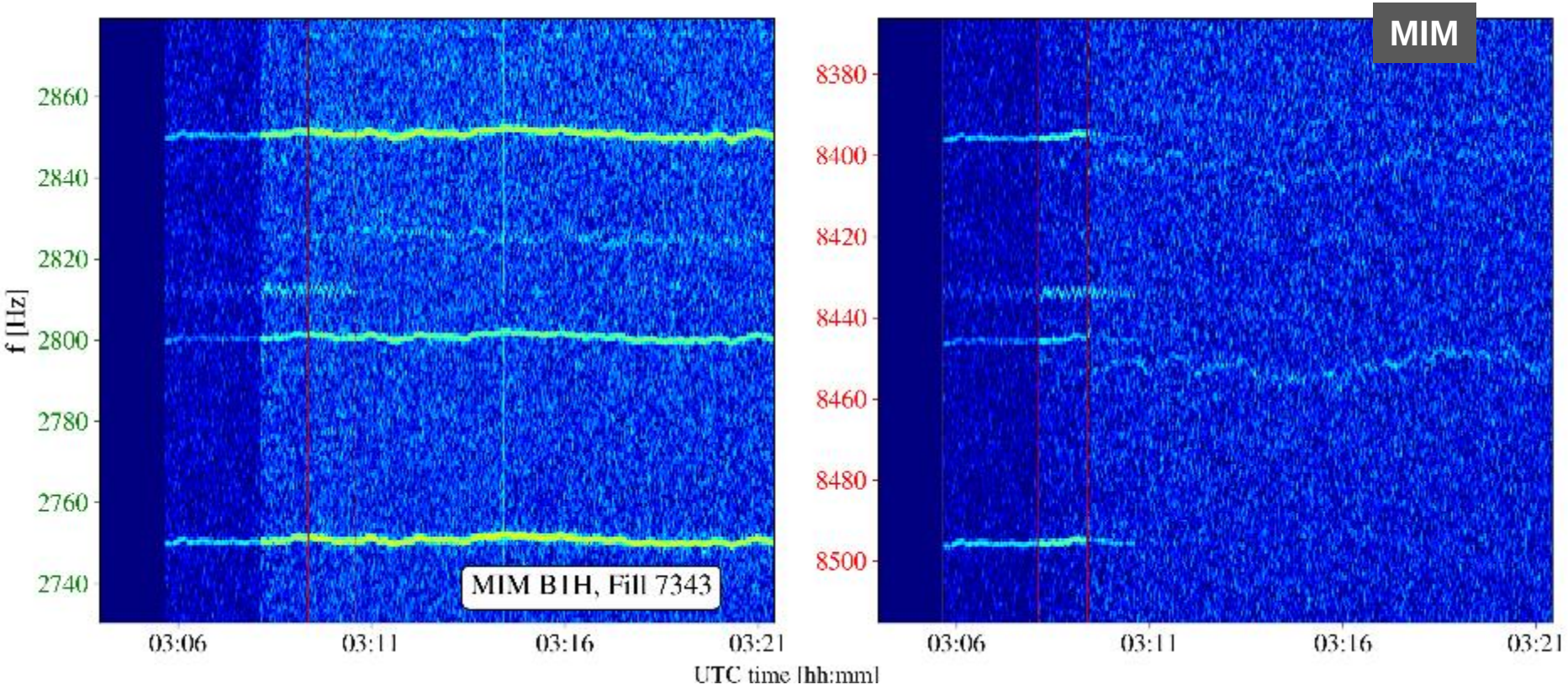
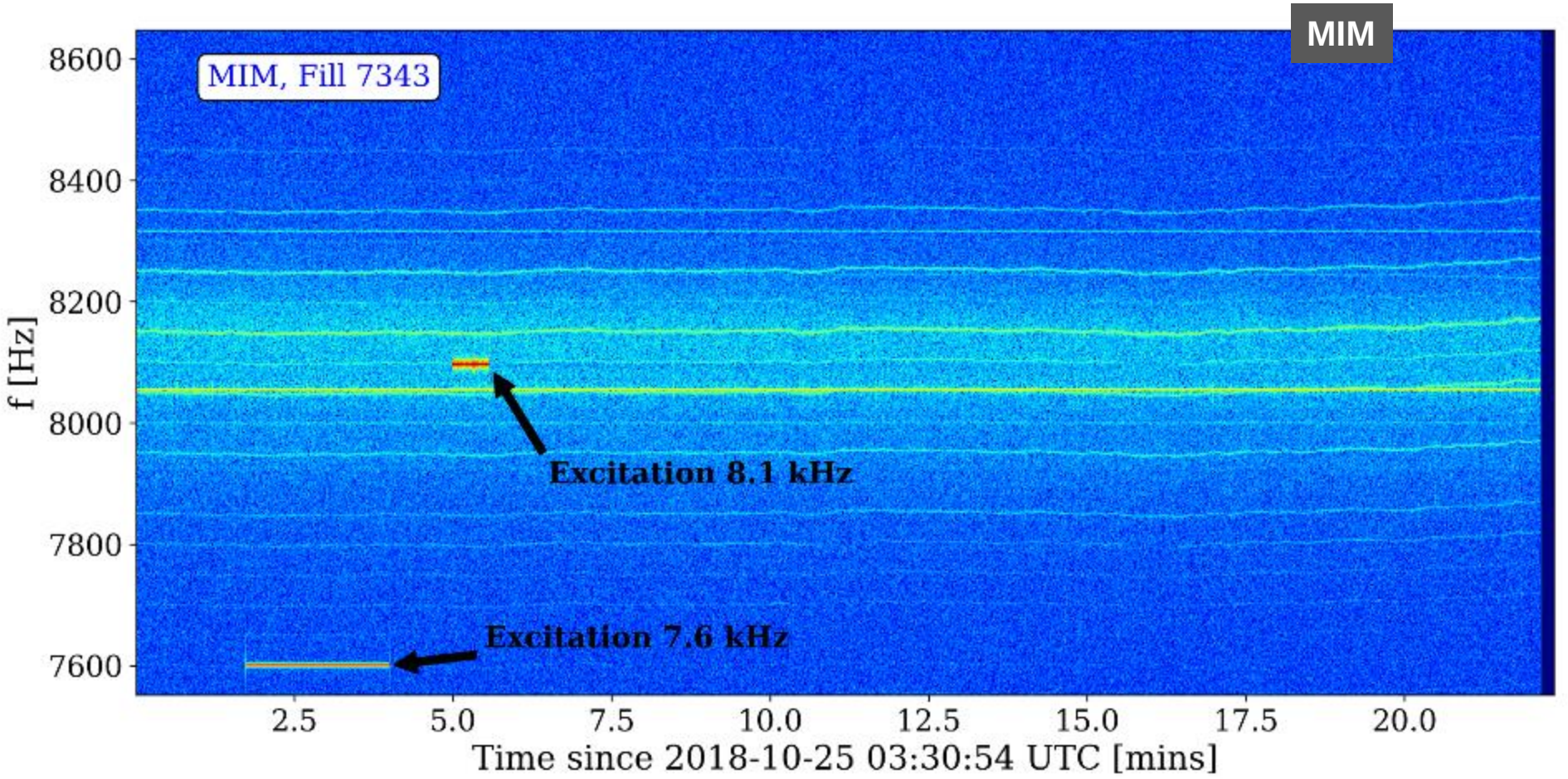


8 kHz cluster

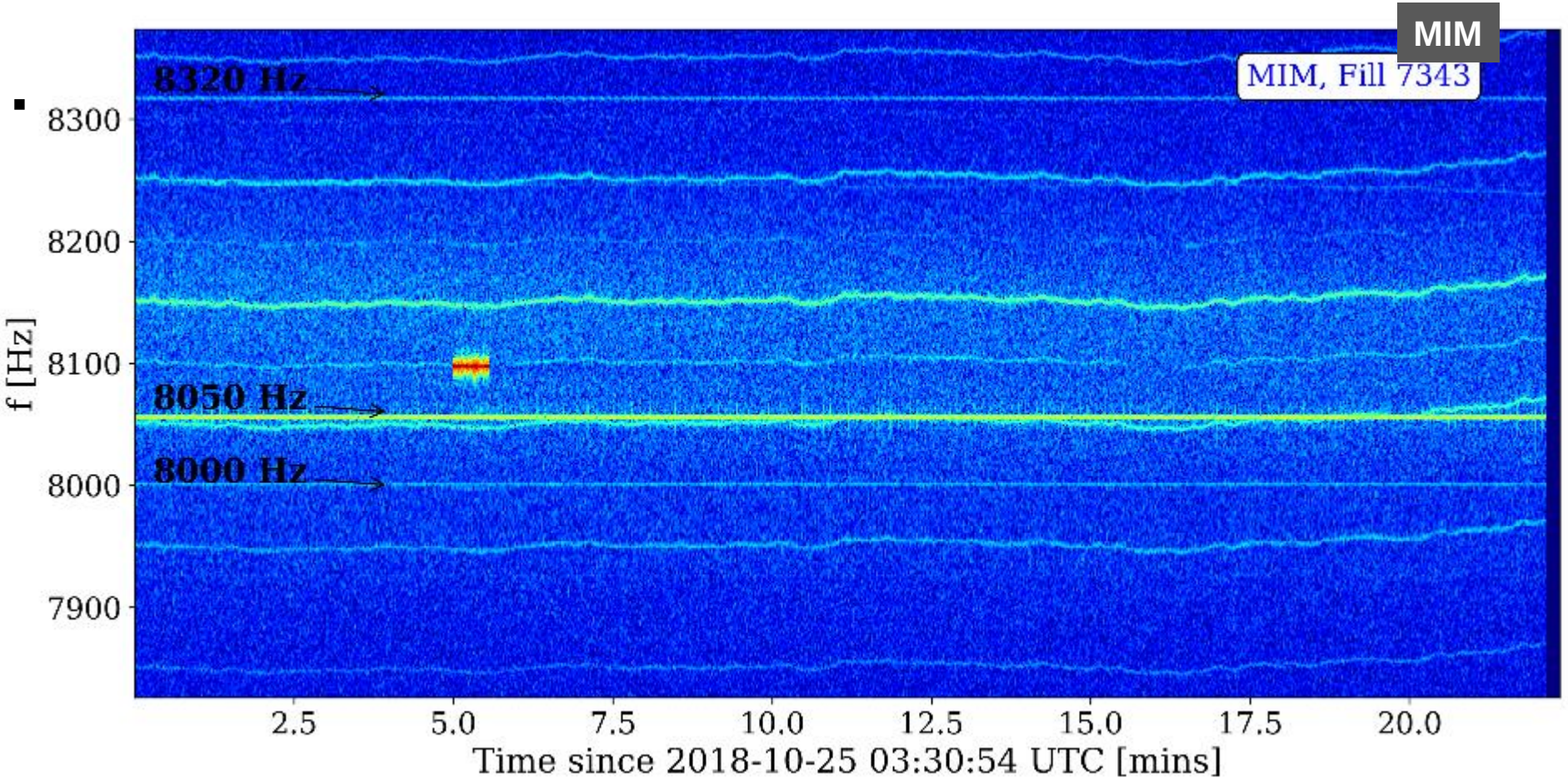


Constant frequencies



Constant frequencies

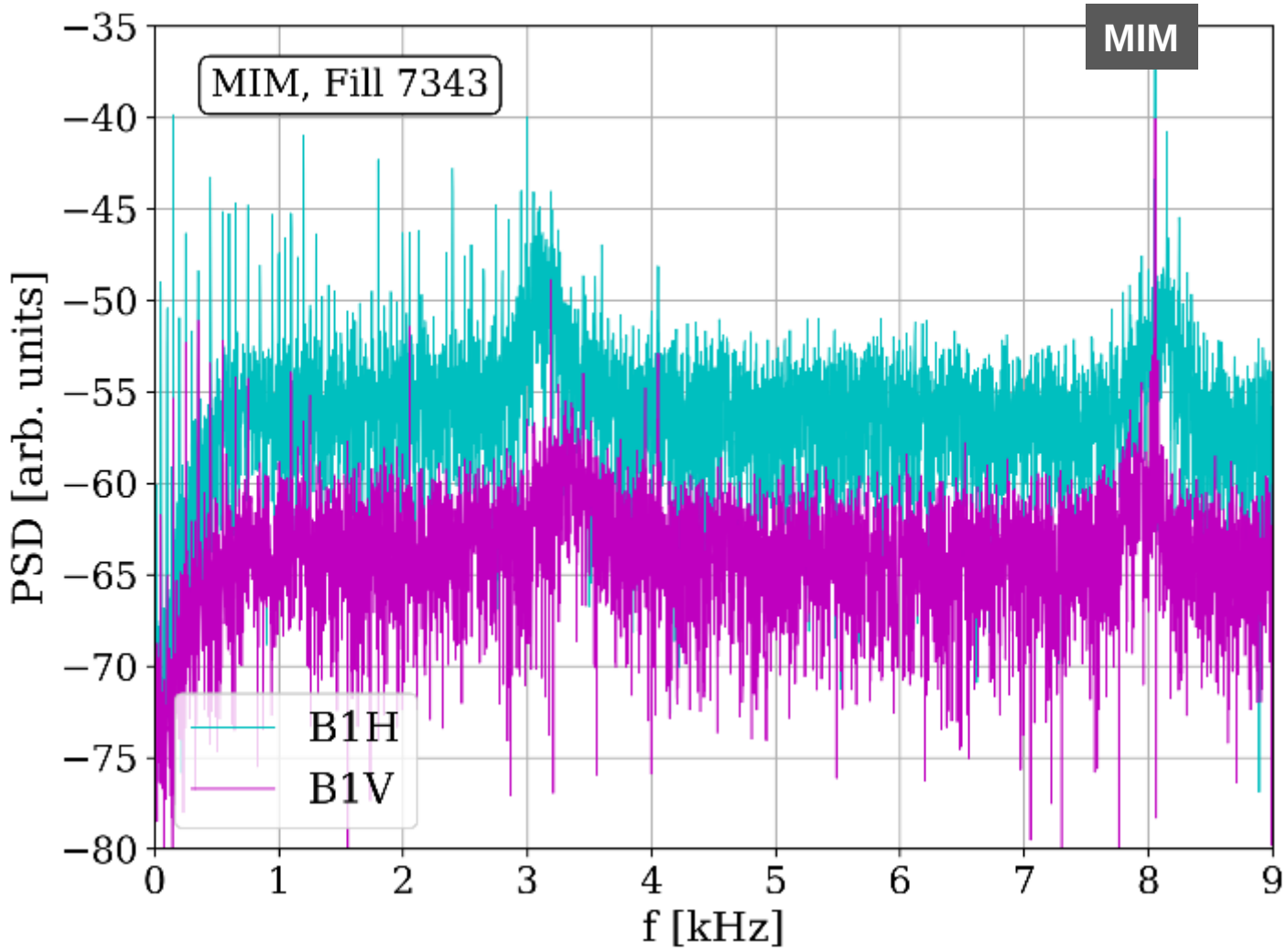
- Apart from the 50 Hz harmonics, there are regular clocked frequencies in the spectrum (SM PCs? Acquisitions cards?)
- Visible both in the MIM & ADTObsBox
-



Constant frequencies

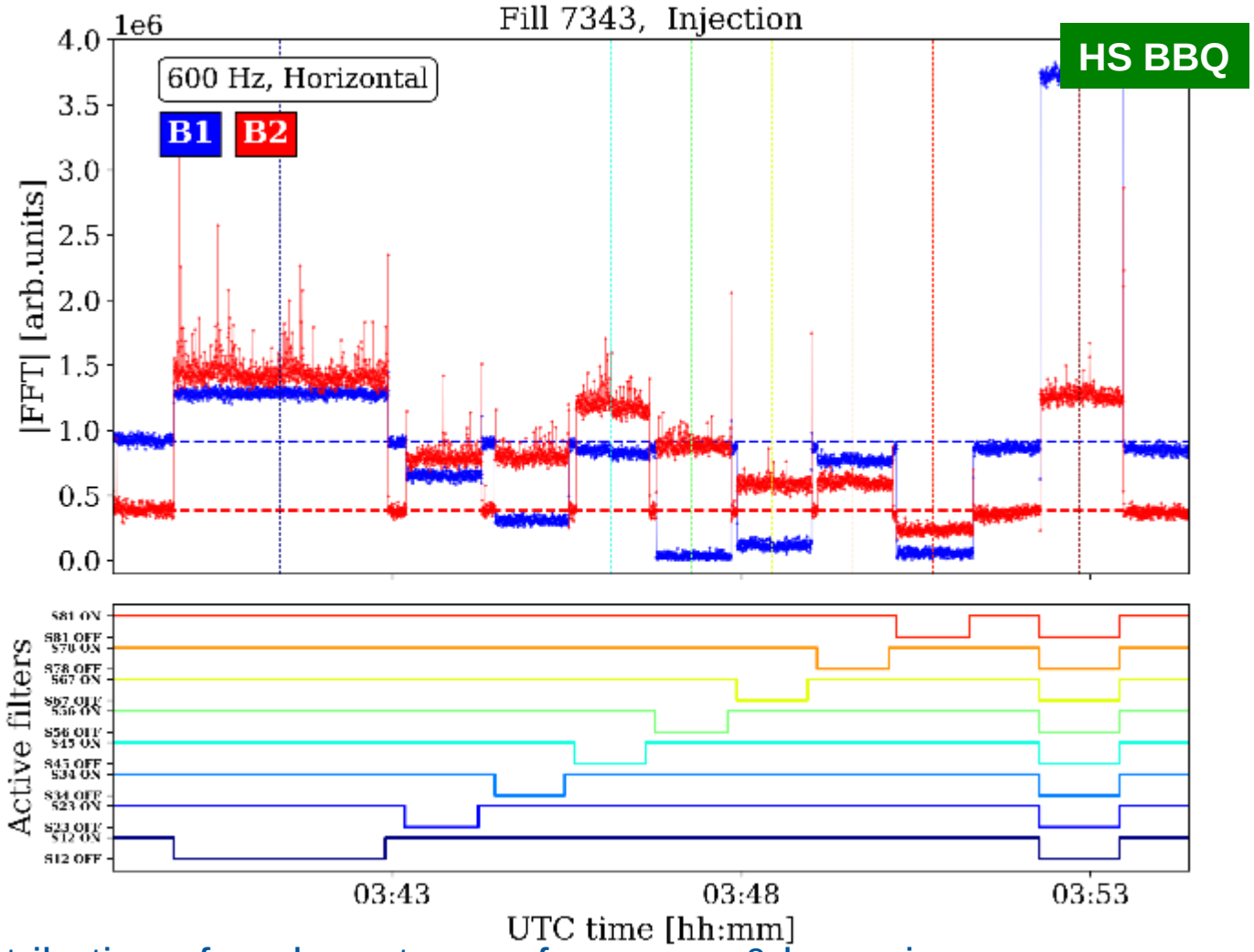
One of them (8050) is very strong in the vertical plane compared to the rest of the spectrum.

Aliased as 3195.5 Hz in the BBQ



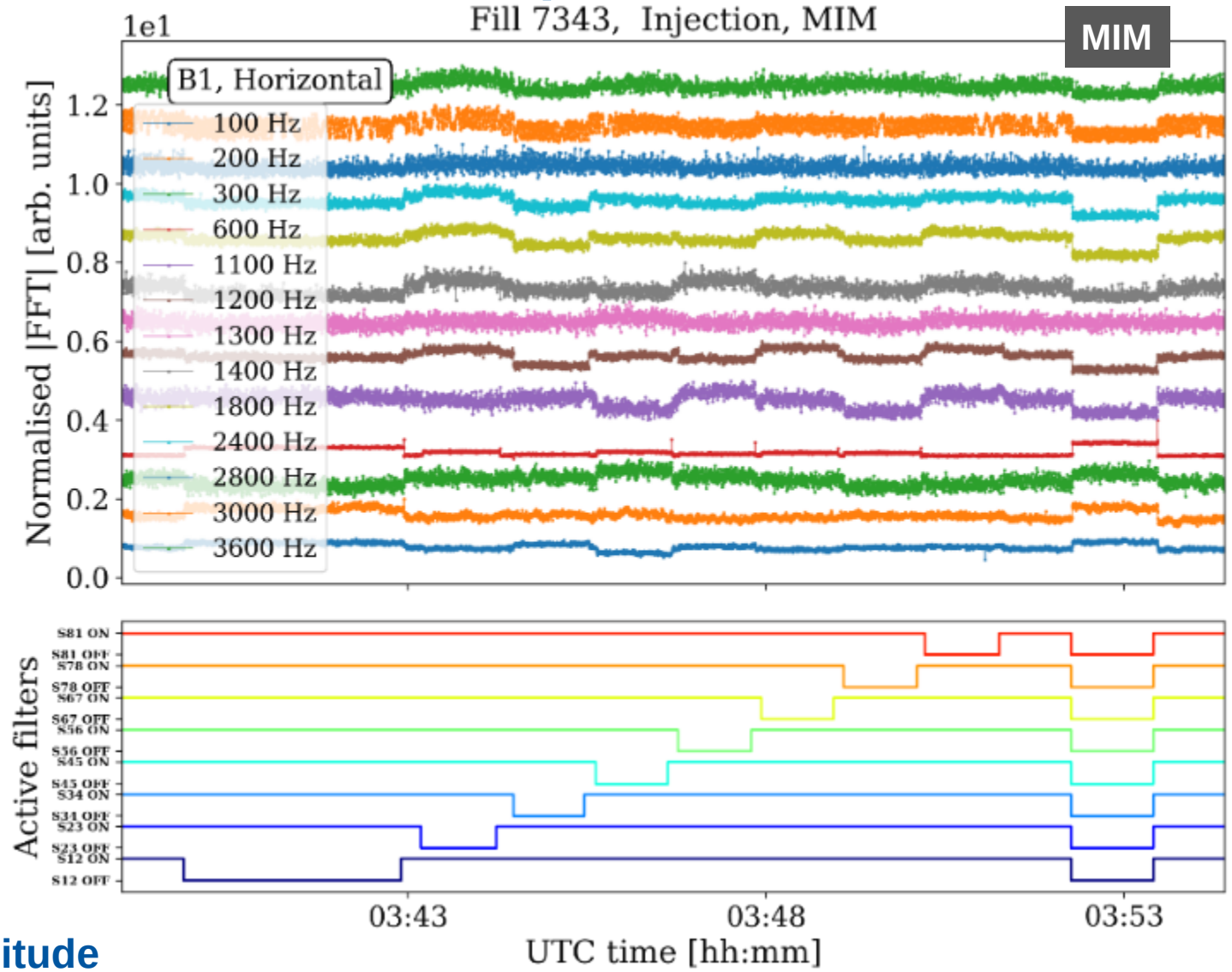
Active Filters: Amplitude evolution

Amplitude



Map of the contribution of each sector per frequency & beam in terms of amplitude at injection ☑

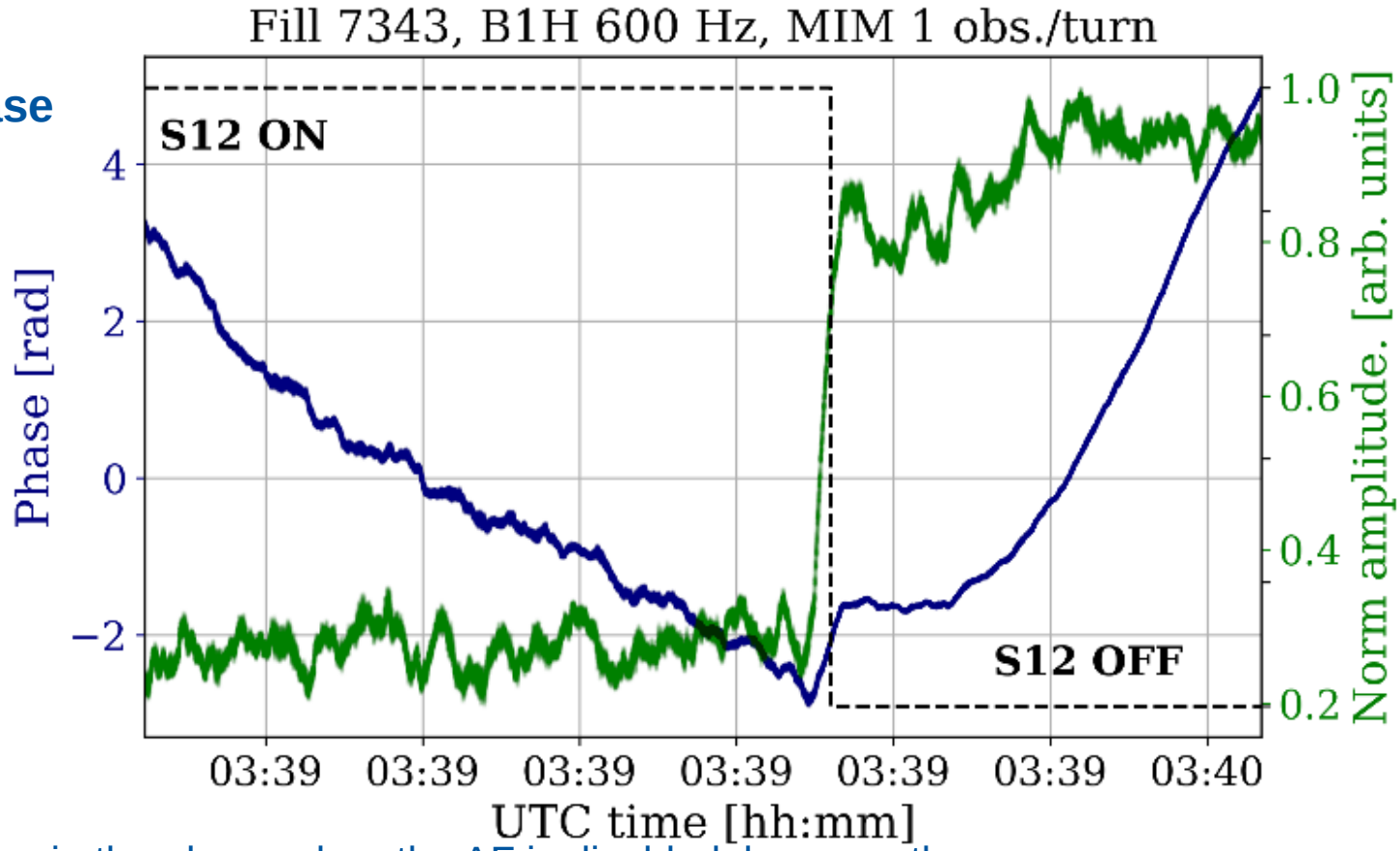
Active Filters: Amplitude evolution



Amplitude

Active Filters: Phase evolution

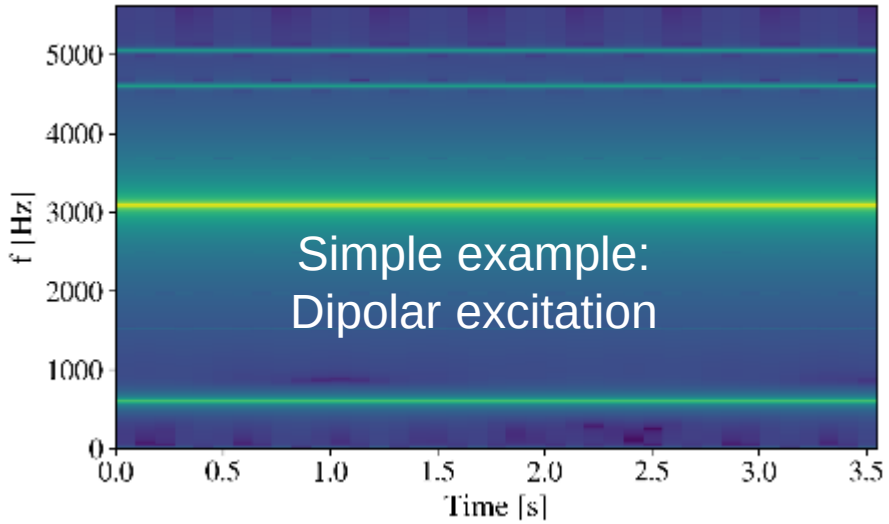
Phase

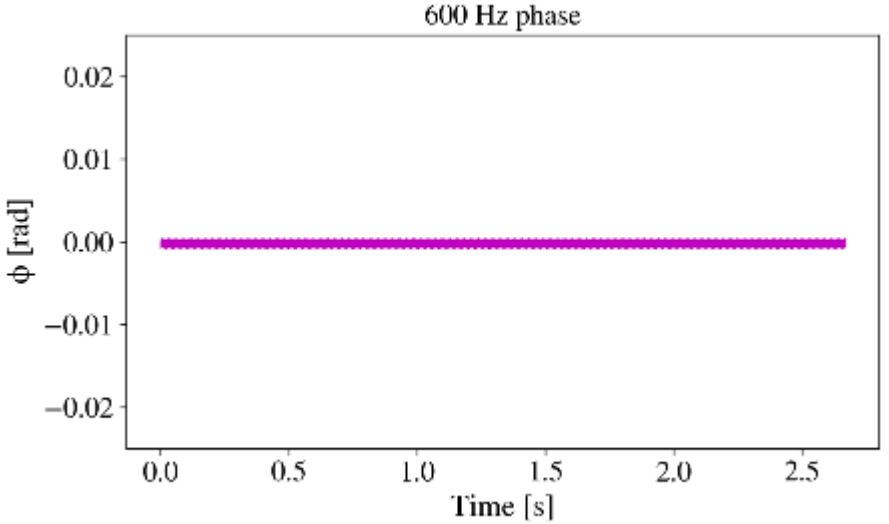


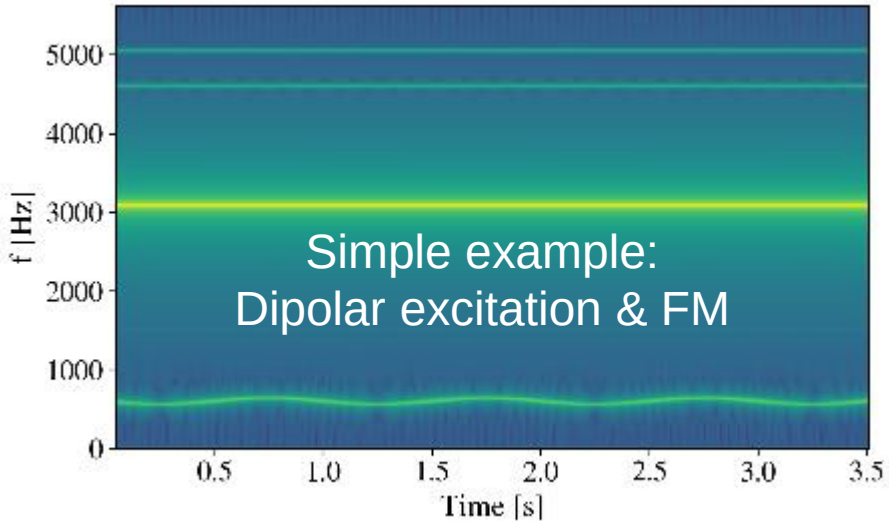
There is a jump in the phase when the AF is disabled, however the phase is not constant before or after the test. Is this correlated with the modulation from the mains?→ simple example

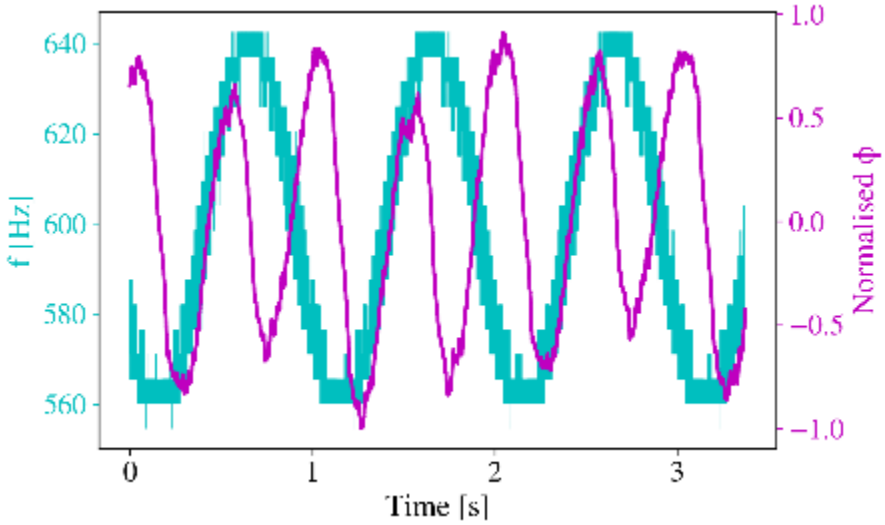
Map of the contribution of each sector per frequency & beam in terms of phase at injection ☒

Active Filters: Phase evolution



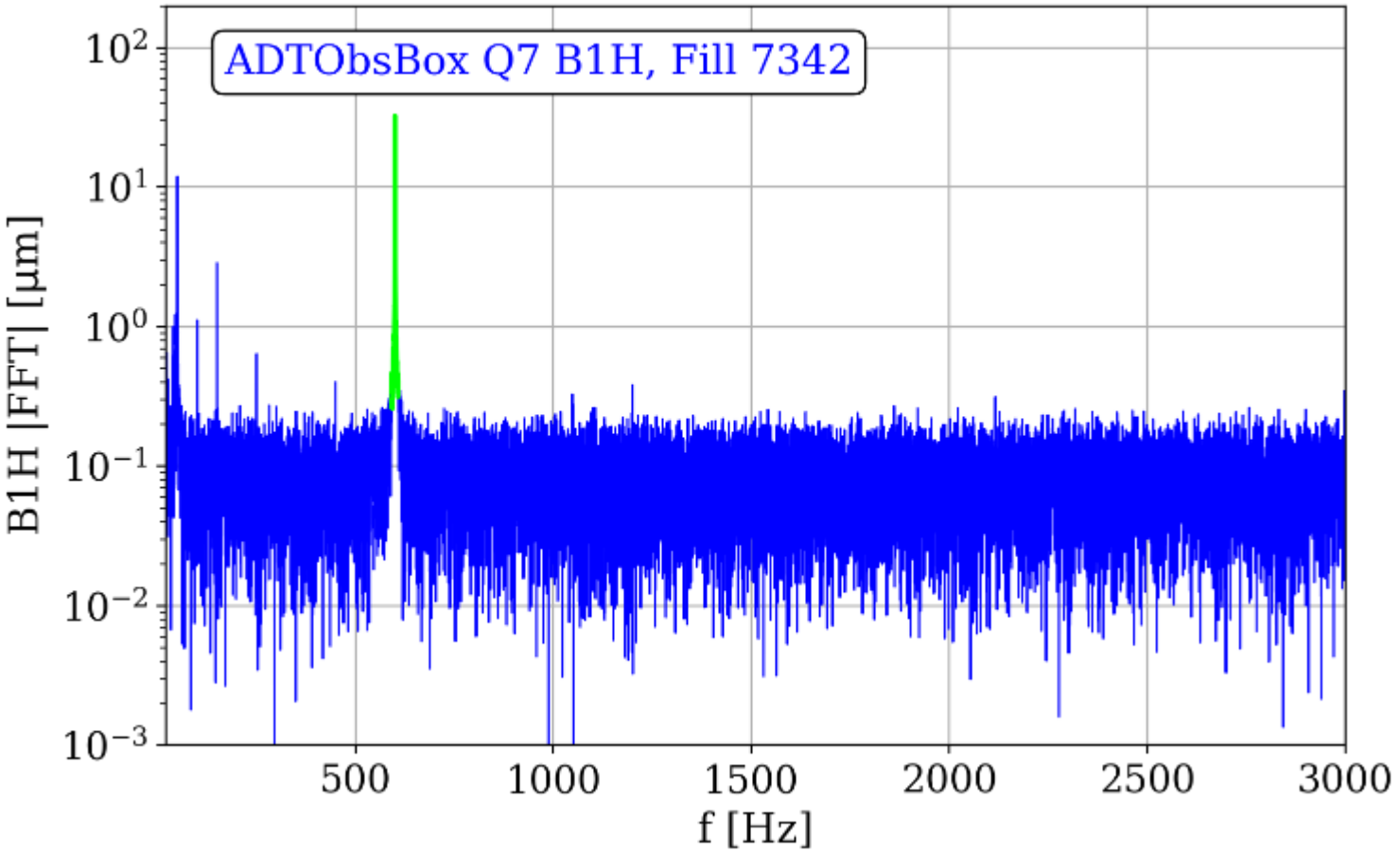






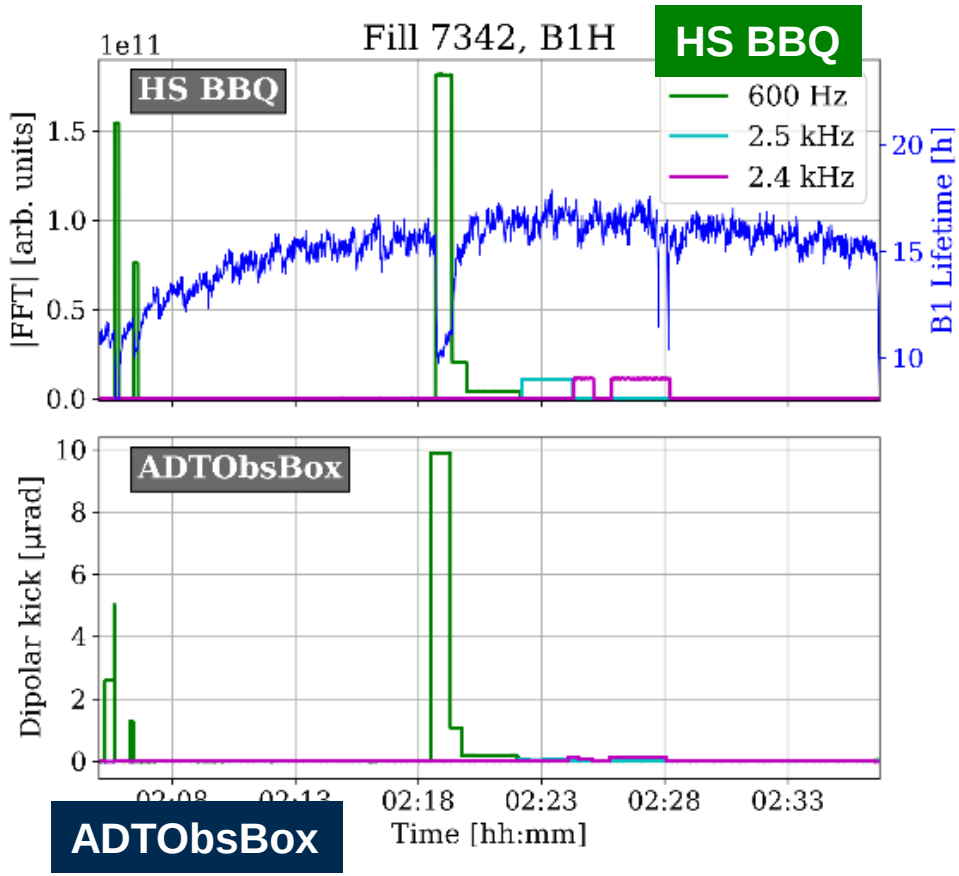
ADT excitations

1. Compute offset by integrating near the frequency of interest.
2. Estimated kick with analytical formula.

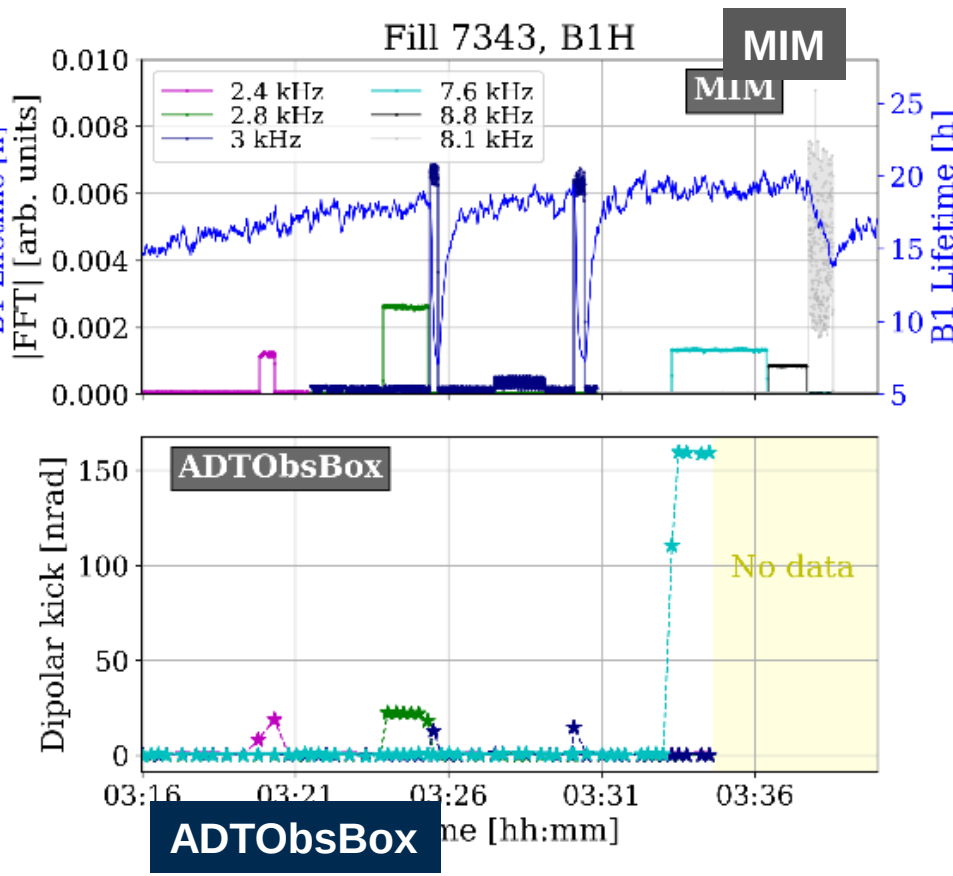


ADT excitations

Fill 7342: ADTObsBox data every minute + instability trigger

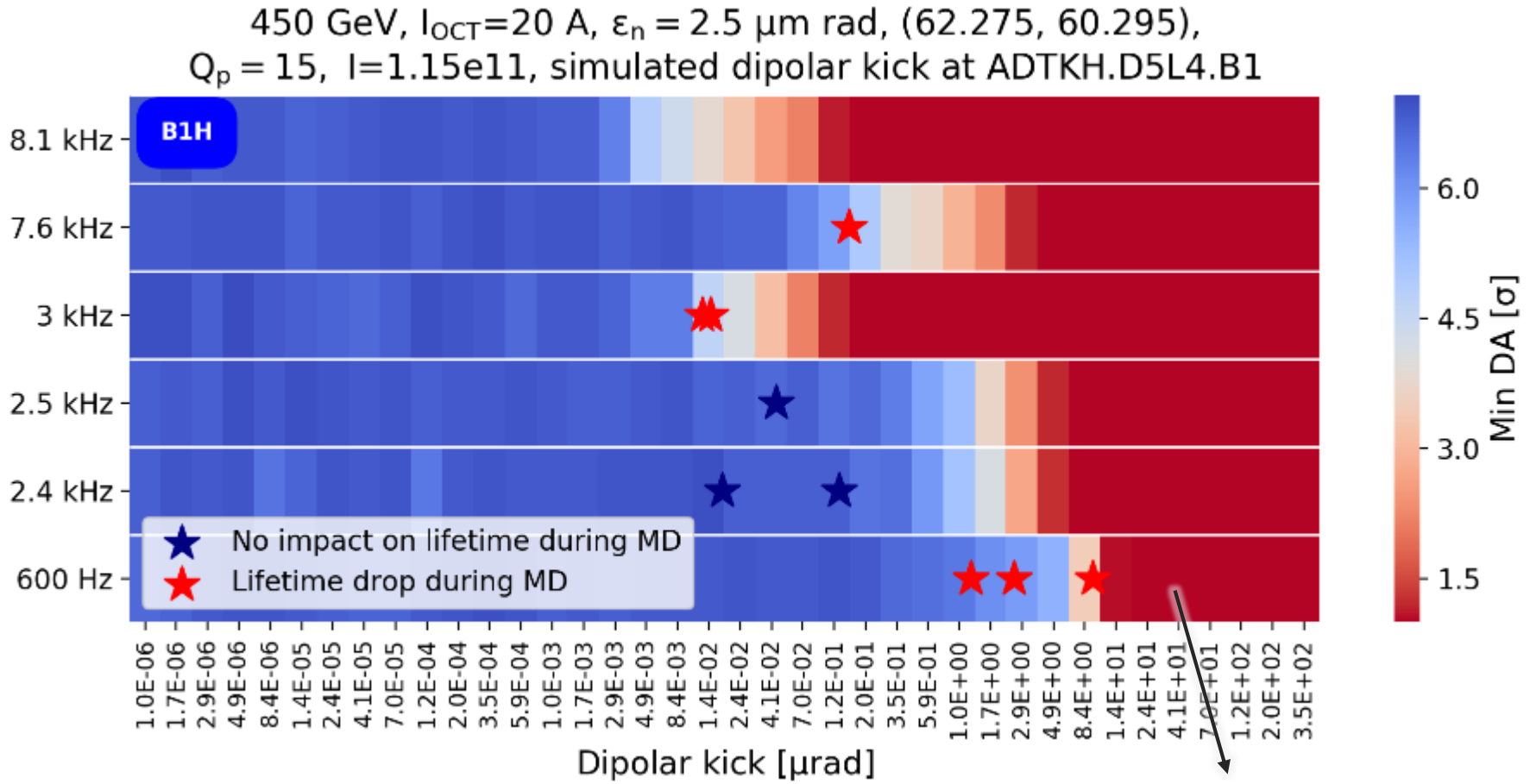


Fill 7343: Instability trigger



ADTObsBox: Estimated kick based on ADTObsBox spectrum + Analytical formula

ADT excitations

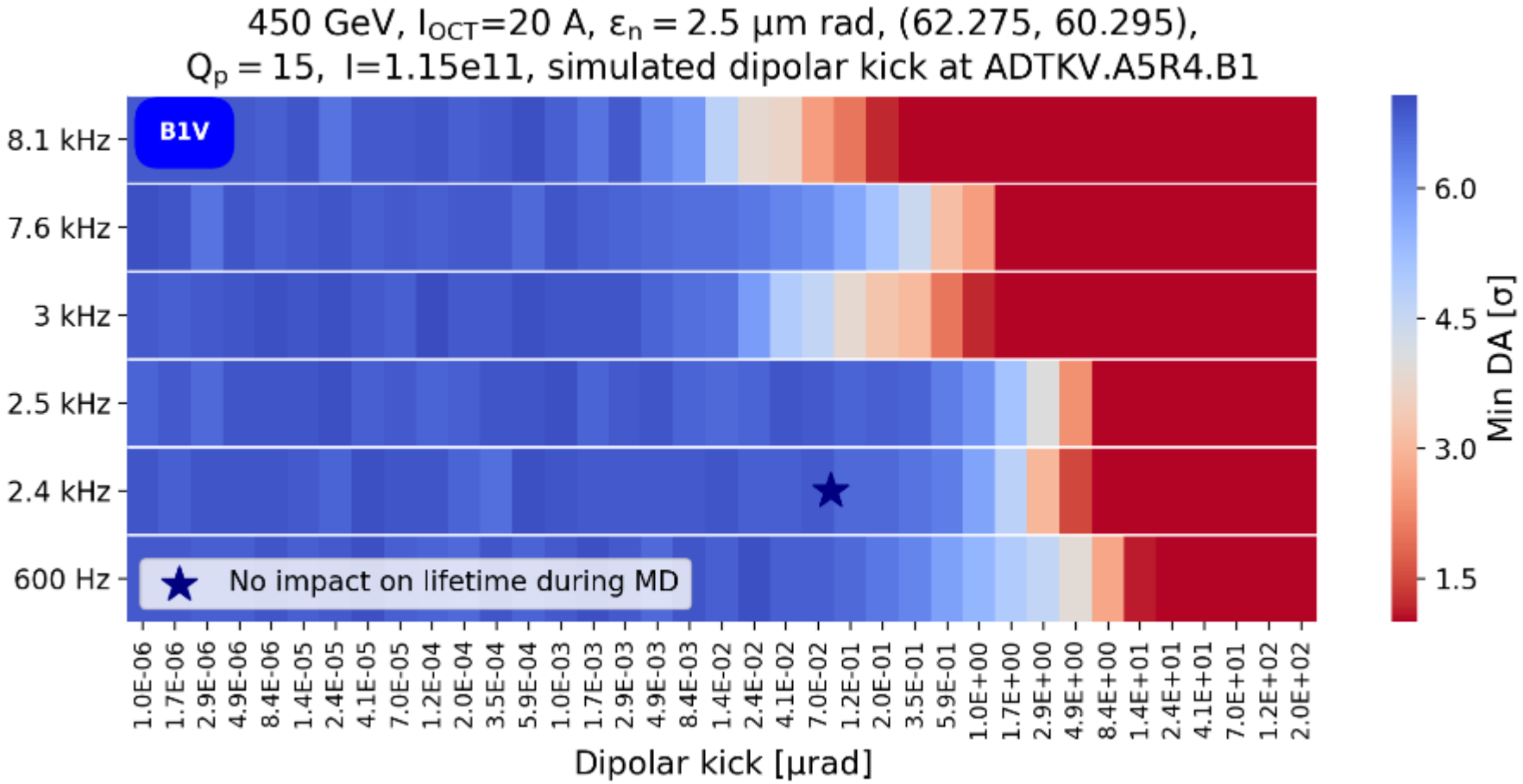


Red star: Reduction of lifetime during the MD

Blue star: No impact on lifetime

DA simulations with injected noise at the location of one of the ADT kickers

ADT excitations

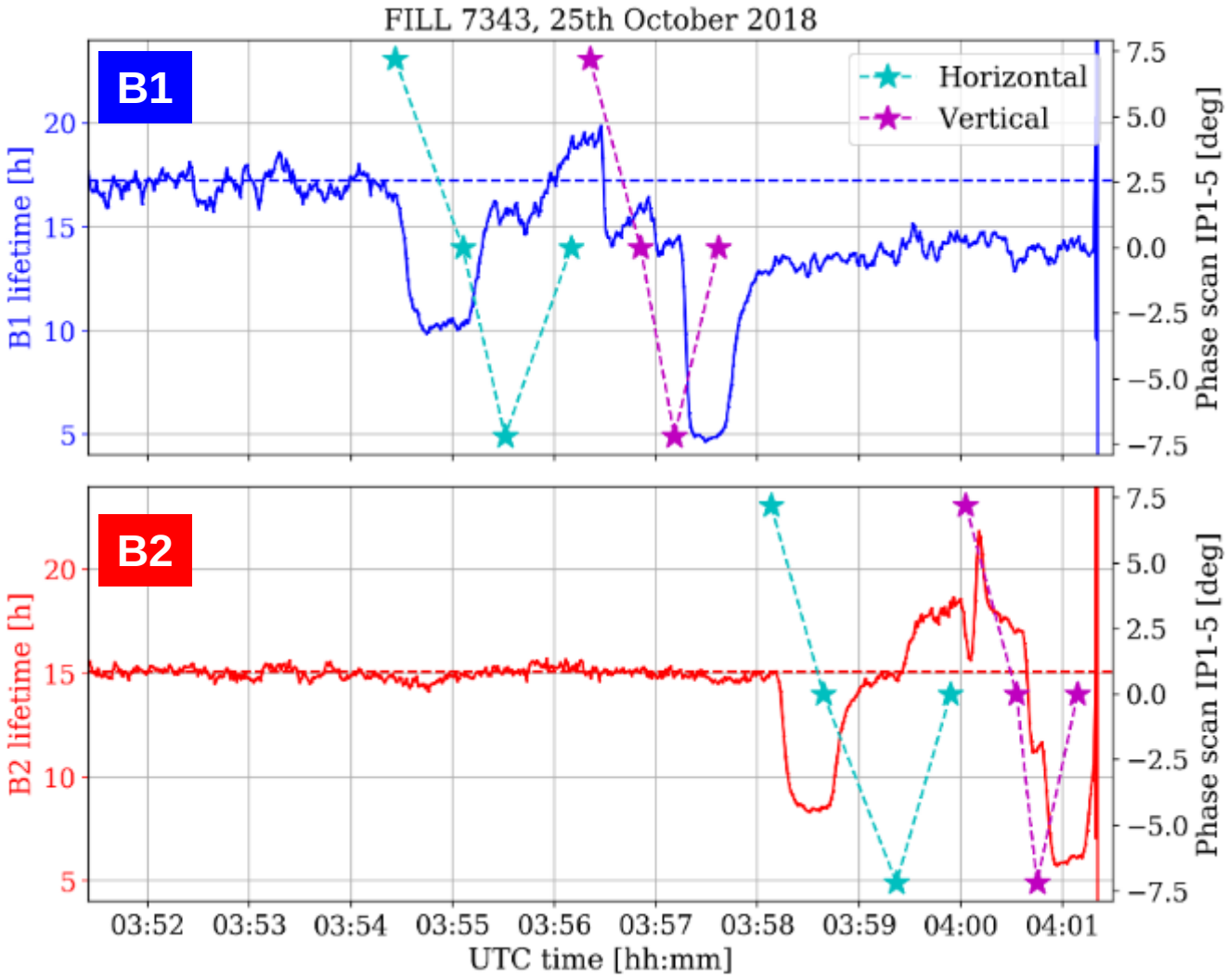


DA noise simulations and lifetime reduction during the excitations **agrees very well**. **<u>However</u>**, the maximum kicks computed by the ADT parameters (thanks to D. Valuch & M. Soderen), show that the estimated kicks are many orders of magnitude higher (possible reason: baseline noise included during the integration?)

IP1/5 phase scan

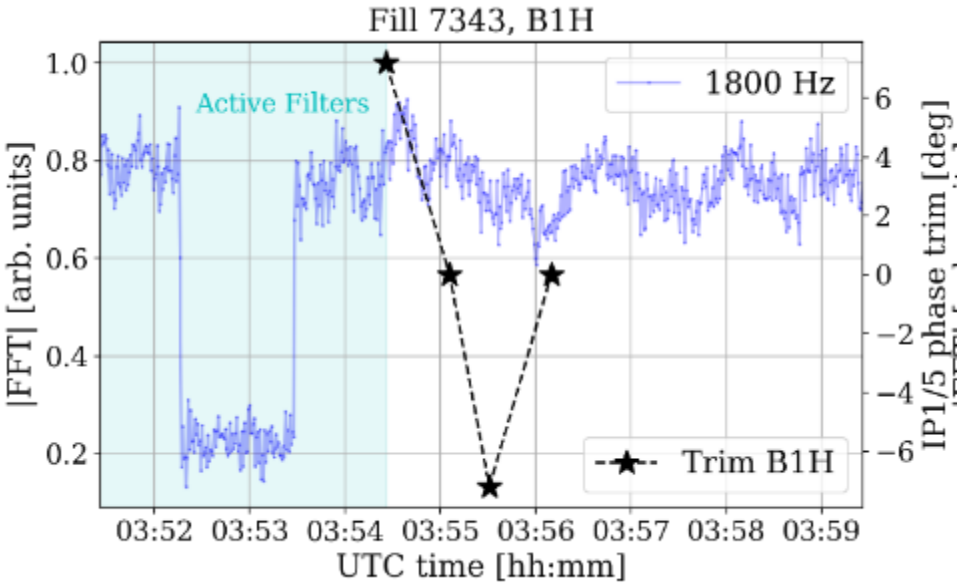
Horizontal

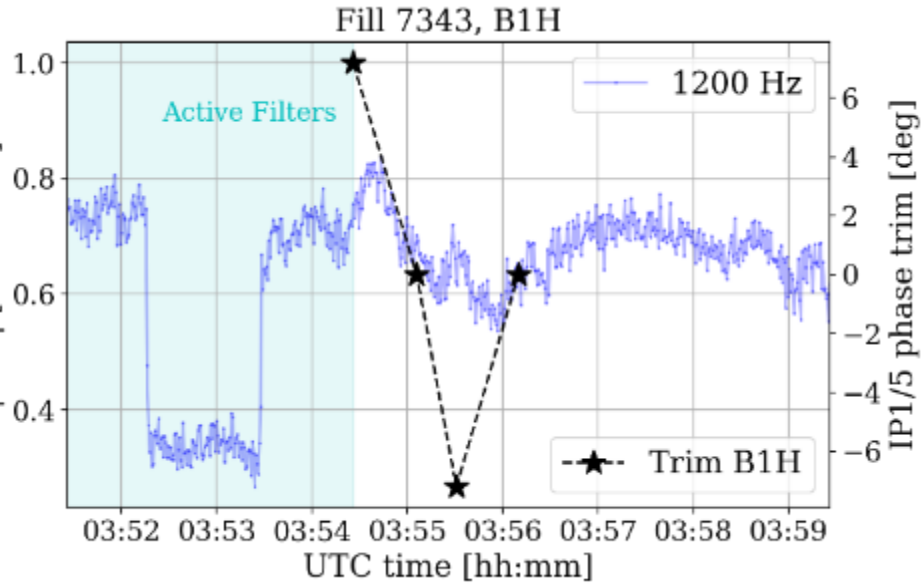
Vertical



IP1/5 phase scan

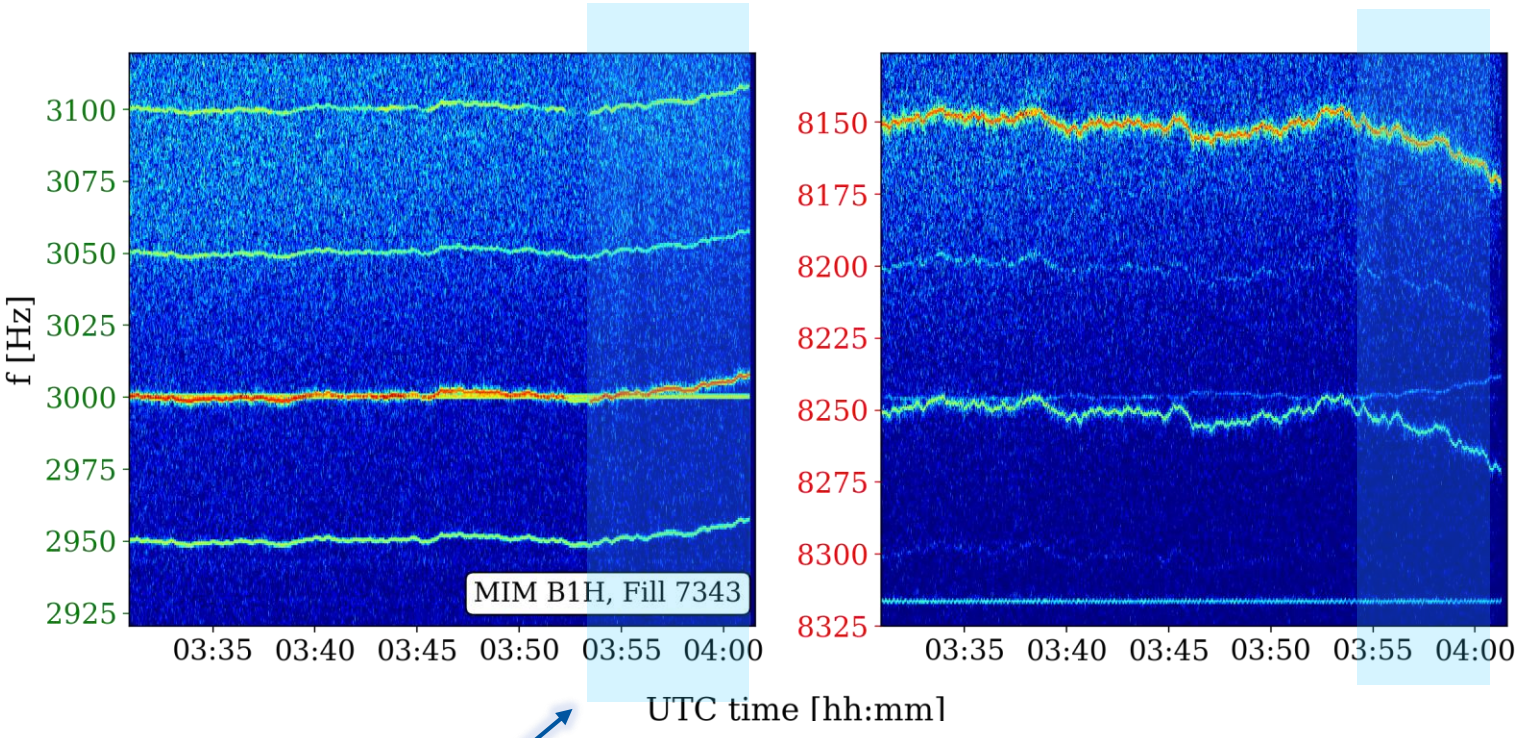
No change in the amplitude evolution of the harmonics during the tests. Lifetime variations are not correlated with the 50 Hz harmonics





Reproduce the results of the IP1/5 phase scan ☒

IP1/5 phase scan

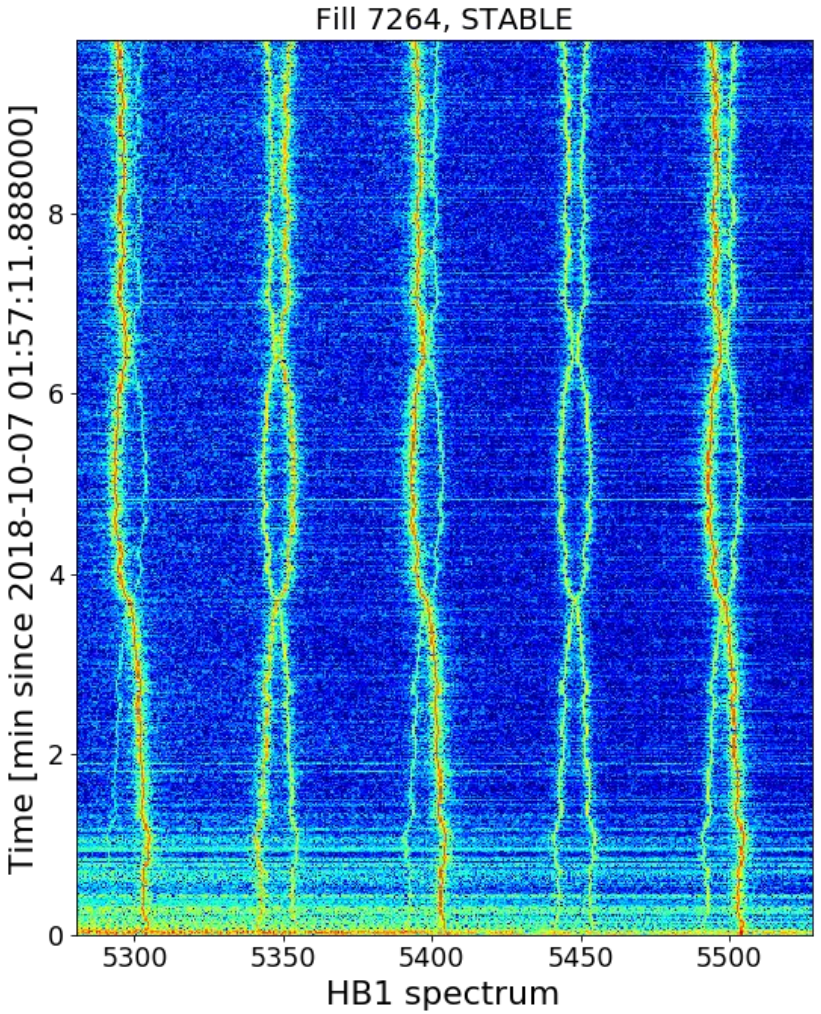


IP1/5 phase scan, drift?

List of open points

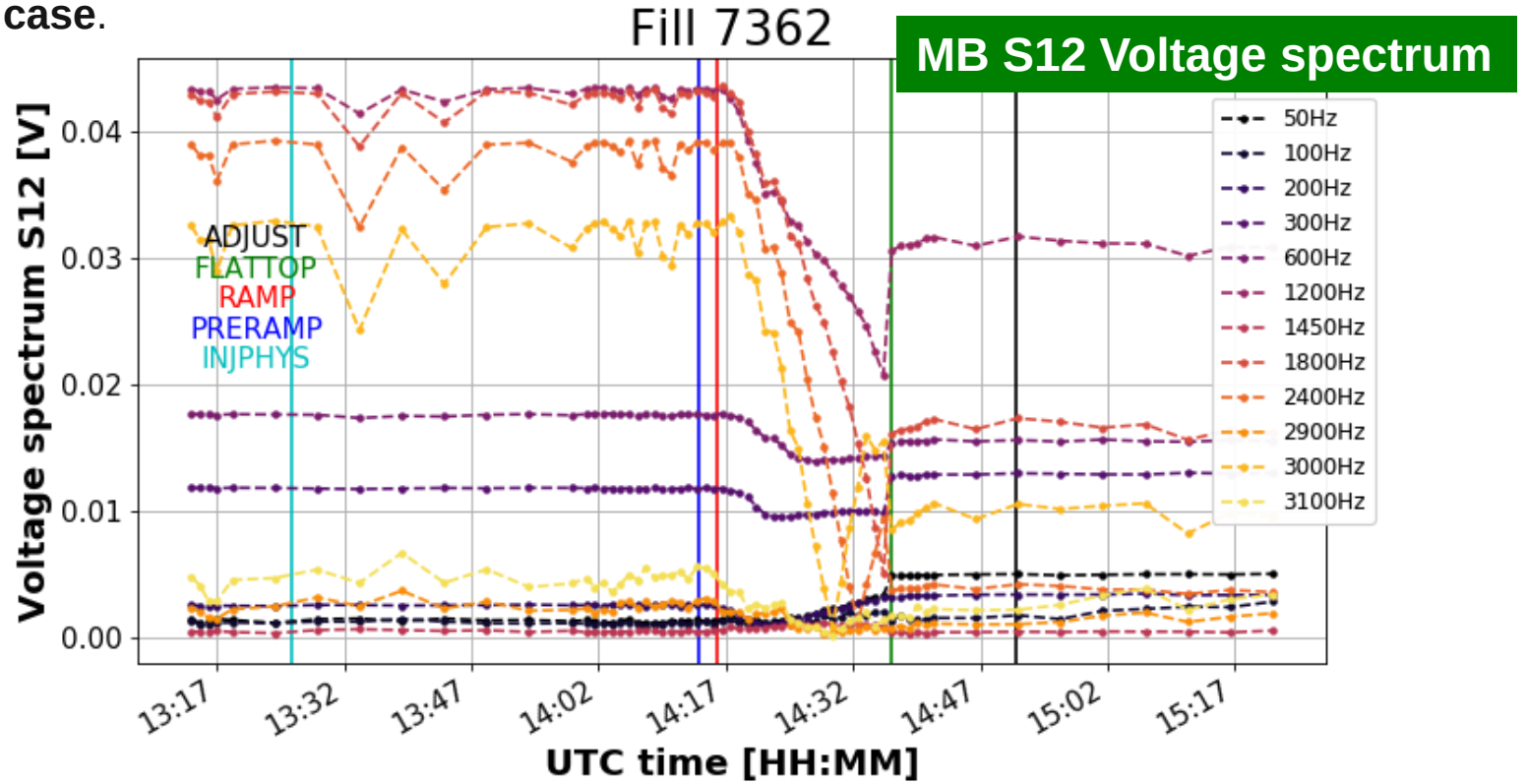
- **Triplet:**

If 8 kHz cluster is a sideband we should not have been able to see the “triplet” (aliased and fundamental will overlap in the HS BBQ spectrum)



List of open points

- **Ramp:**
  - During ramp, we do not see any attenuation of the lines (to be verified with a more refined analysis and possibly with MIM data if available)
  - As the beam rigidity increases, the kicks should cause a smaller deflection and the lines should attenuate.
  - Unless, the noise from the MBs power converters increases during RAMP. **This is not the case**.



Conclusions

8 kHz cluster

- Observations with the MIM indicate that the 8 kHz cluster is either the sideband of the harmonics of 50 Hz in the 3 kHz regime or the result of a sampling error in high sampling rate measurements.

Constant frequencies

- Apart from harmonics of 50 Hz**, regular clocked frequencies** has been identified in the spectrum of both the ADTObsBox and MIM. **One of them is particularly strong in the vertical plane compared to the rest of the spectrum**. The source needs to be identified. If artifacts are excluded, their potential impact needs to be determined.

Active filters:

- The changes in the beam response for some of the 50 Hz harmonics at injection has been validated. **All eight sectors contribute to this effect**.
- We have a **map of the relative amplitude contribution of each sector**.
- For the phase contribution, additional information are needed.

ADT excitations:

- **The DA noise simulations and the lifetime reduction during the MD agree very well**.
- However, there is a discrepency between the maximum kick obtained by the ADT parameters and the estimated one based on the beam offset.

IP1/5 phase scan:

- The variation of the beam response at some of the 50 Hz harmonics observed at top energy was not reproduced at injection.

Next steps

- Correct for dephasing between trains in the ADTObsBox bbb data and how this affects the spectrum with trains.
- Verify that there is no attenuation during RAMP with a more refined analysis (also with MIM data?)
- Verify and identify the constant frequencies in the spectrum, also at top energy
- Remove baseline noise when integrating to compute the offset from the ADTObsBox data and see if estimated and maximum kicks converge to similar values.

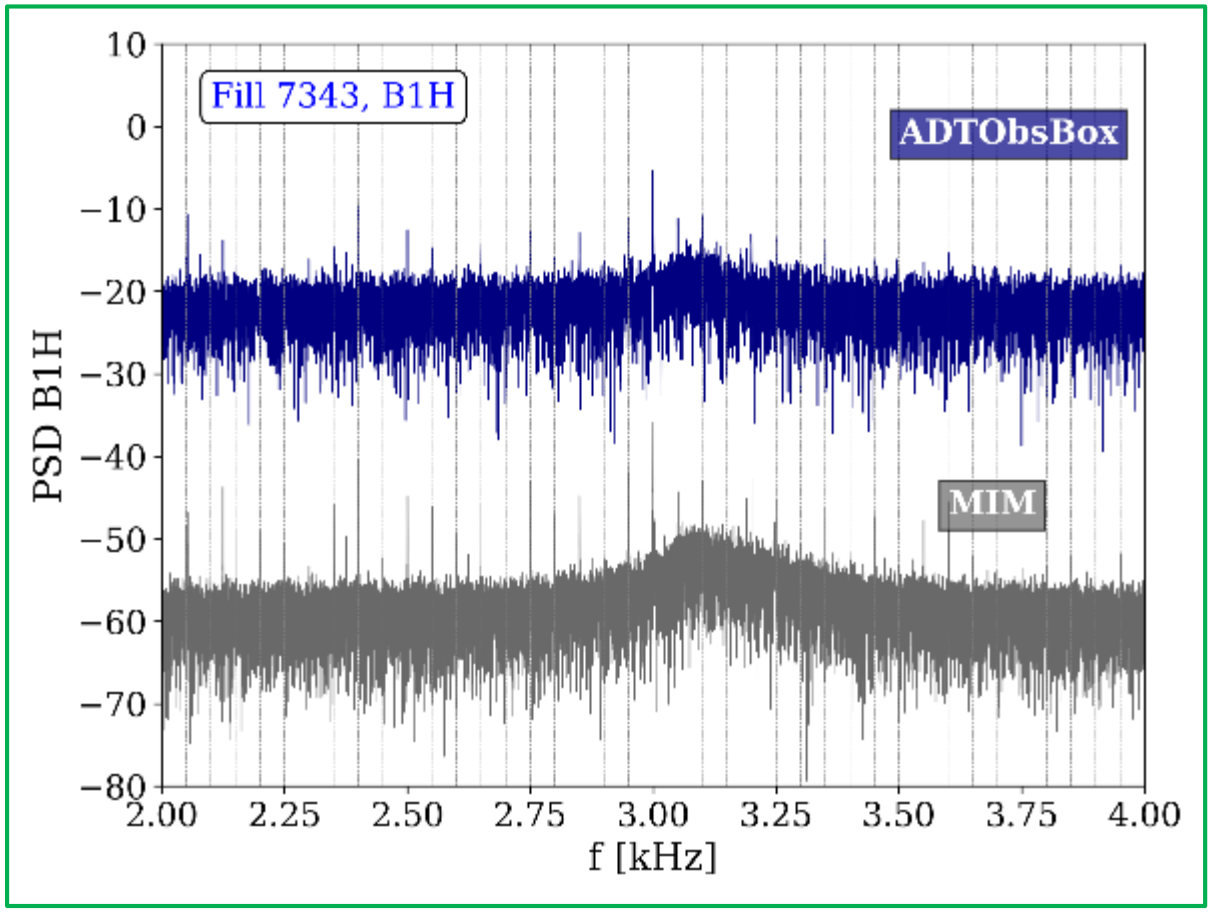
…

Backup

Motivation

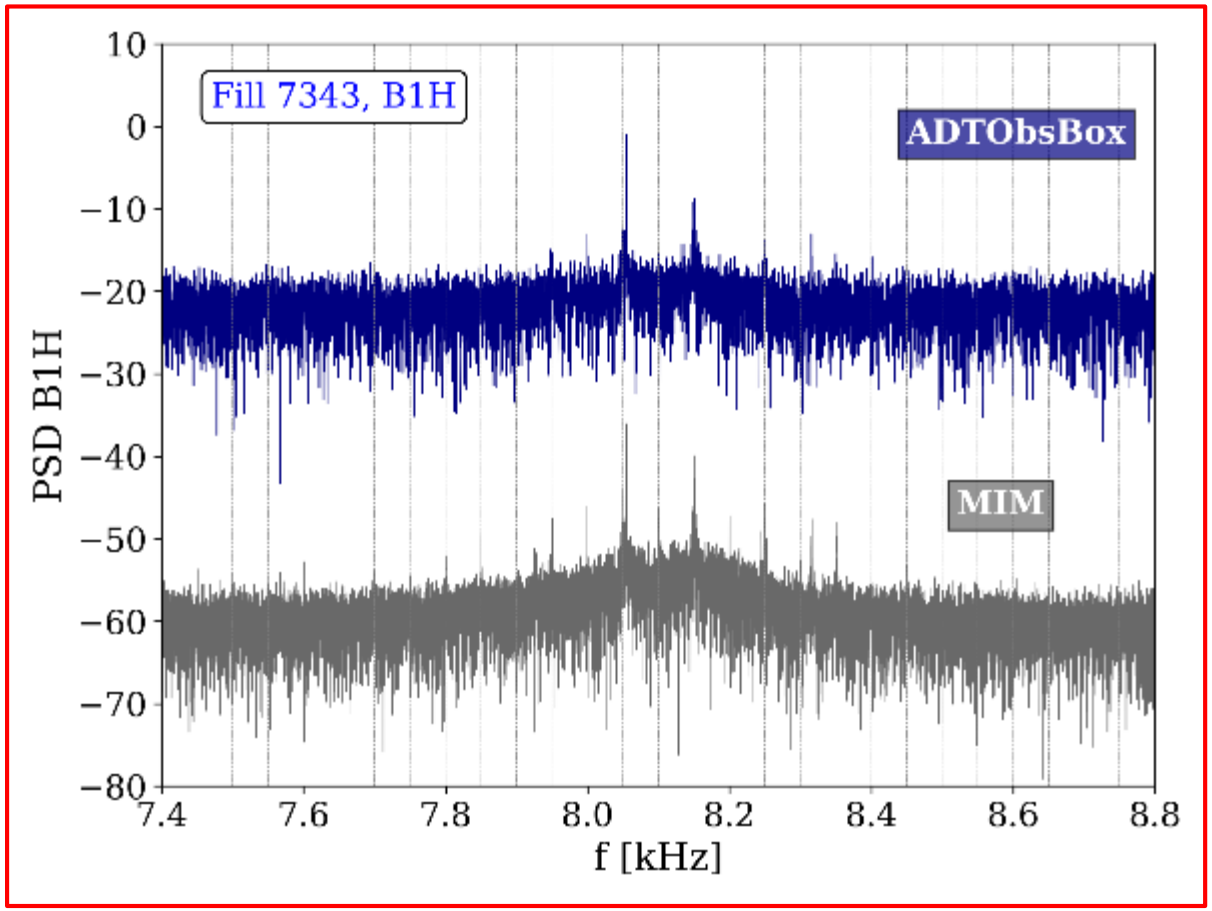
1) **<u>8 kHz cluster:</u>** What is the origin of the 50 Hz harmonics in the 8kHz regime? Is there a similar time evolution between fundamental and high frequency components?

Consistent between instruments



Motivation

1) **<u>8 kHz cluster:</u>** What is the origin of the 50 Hz harmonics in the 8kHz regime? Is there a similar time evolution between fundamental and high frequency components?

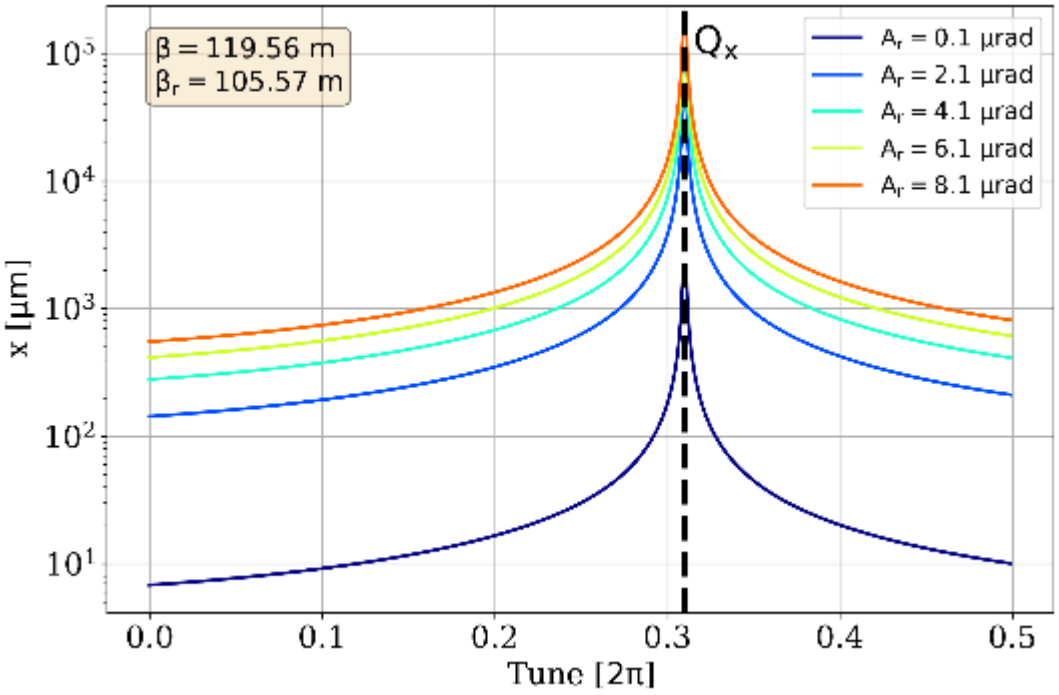


Analytical form for modulated dipolar kicks

- Estimated offset at the observation point in the location s from modulated dipolar kicks:

$$|\mathrm{X(s)}| = \sum_{j=1}^{k} \frac{\sqrt{\beta_j \beta(s)}|A_j|}{|1 - e^{i2\pi(Q_r - Q_x)}|}$$

This can be inverted in order to estimate the kick (e.g from the ADT kickers) based on the offset seen in the beam spectrum.



Analytical form for modulated dipolar kicks

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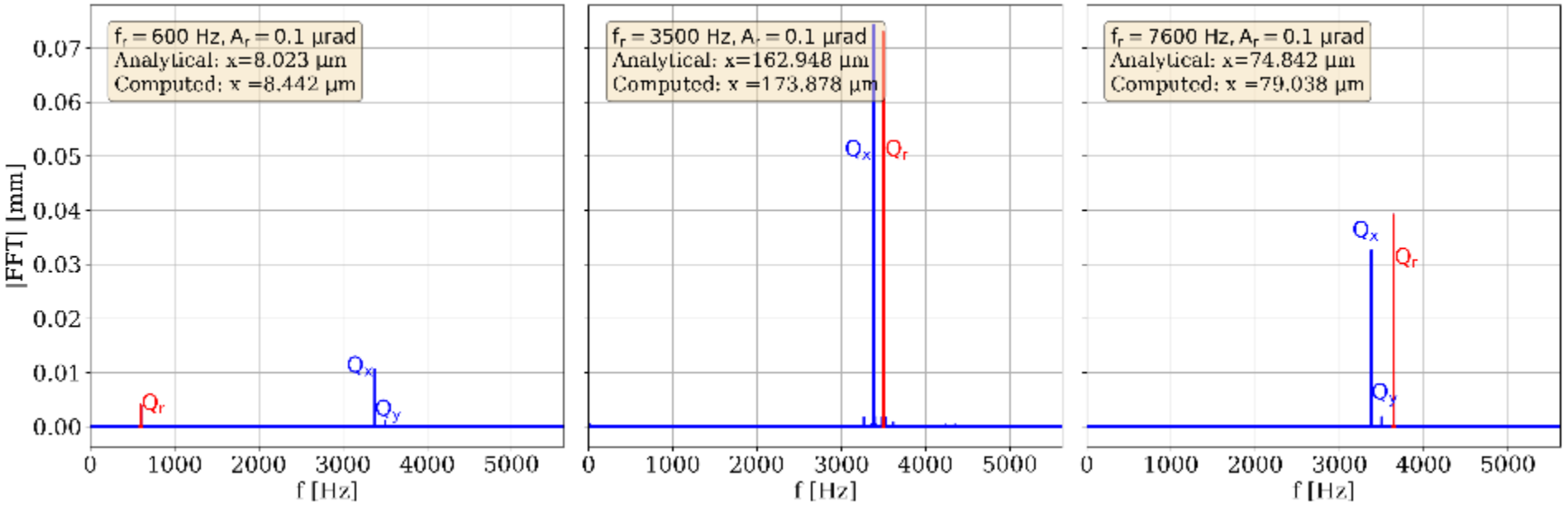
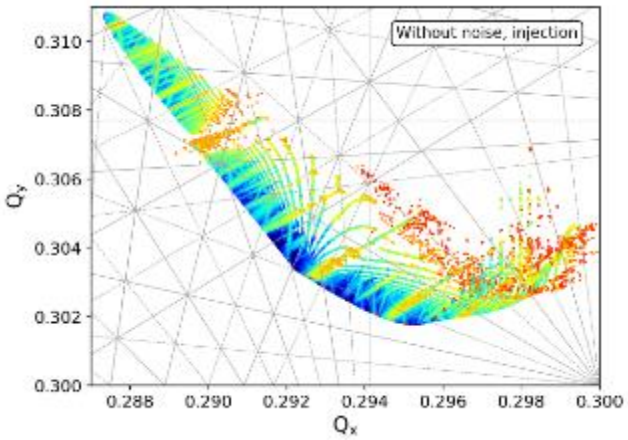
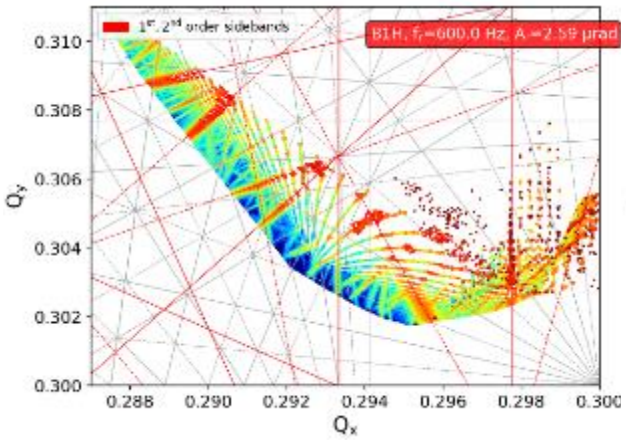
Validation of the formula with SixTrack

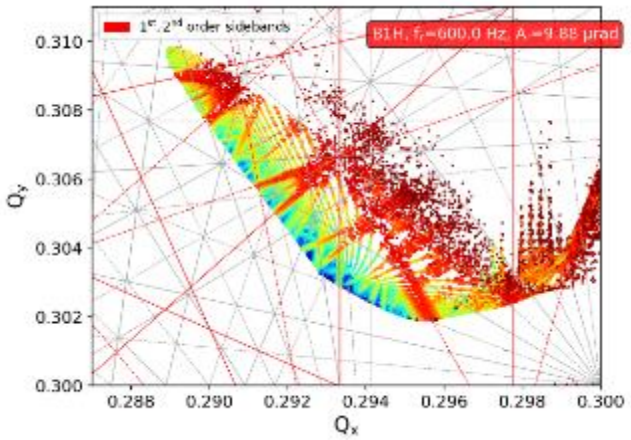


ADT excitations

- Although the excitations are dipolar, frequencies outside of the tune spread lead to lifetime reduction. Feed-down effects from the modulated dipole + non-linear elements produce sideband resonances.







Validate noise DA simulations based on beam offset ☑
Estimated kicks and maximum kicks based on ADT parameters not consistent ☒