The ICEBERG Noise Model

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WireCell Meeting

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Outline

1. Model Noise Conditions
    a. Incoherent Noise
    b. Coherent Noise
2. Simulate Noise
3. Concluding Thoughts

Pre-processing / Selecting Noise Events

I searched for pure noise run.

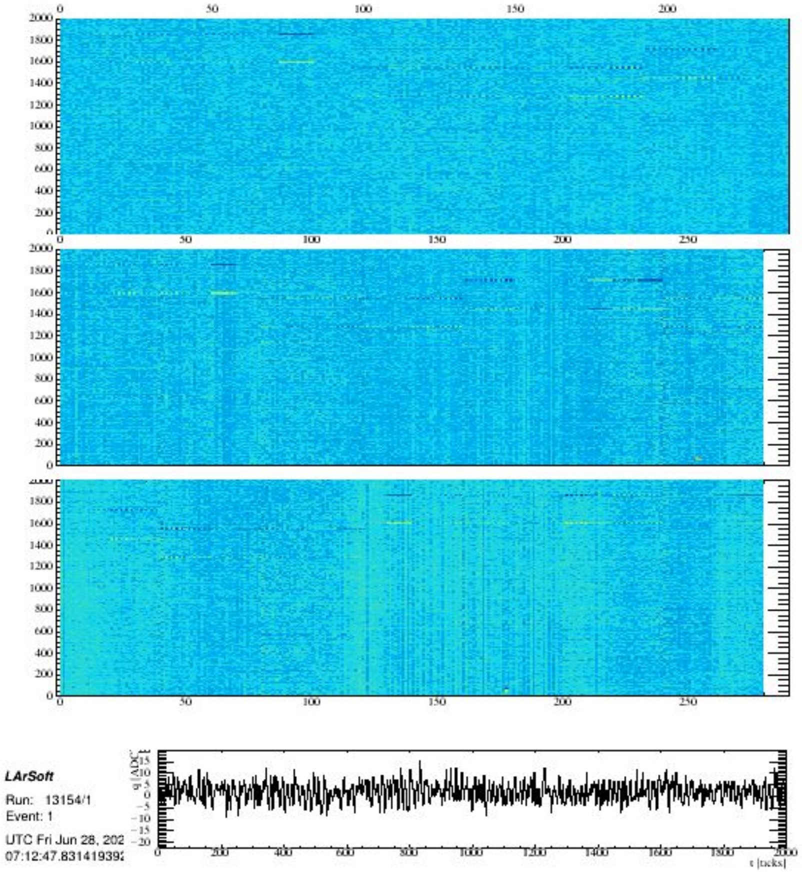
Used Run 13154 – Contains 62 events

Hand-scanned events which contained no cosmic rays – Used 48 events

Characteristic	Value – Run 13154
Pulse_dac	0
Baseline	900/200 mV
Gain	7.8 mV/fC
Peak time	2 us

Model Noise Conditions in ICEBERG

ICEBERG event display, TPC 0



Collection Plane

V Plane

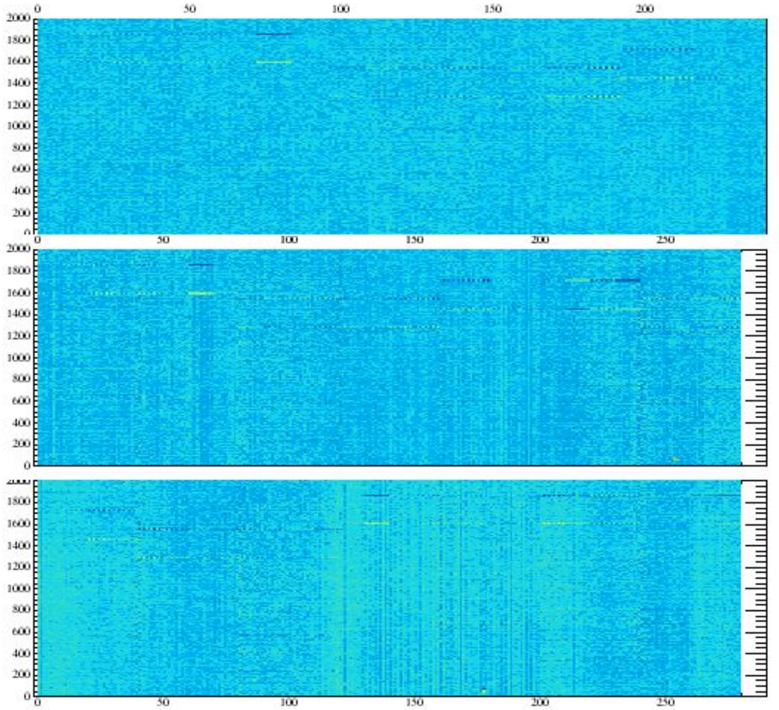
U Plane

Single Wire Waveform

ICEBERG data Run 13154, Event 1

Model Noise Conditions in ICEBERG

ICEBERG event display, TPC 0

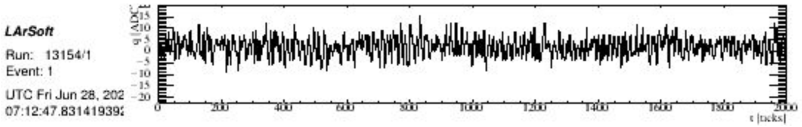


Collection Plane

V Plane

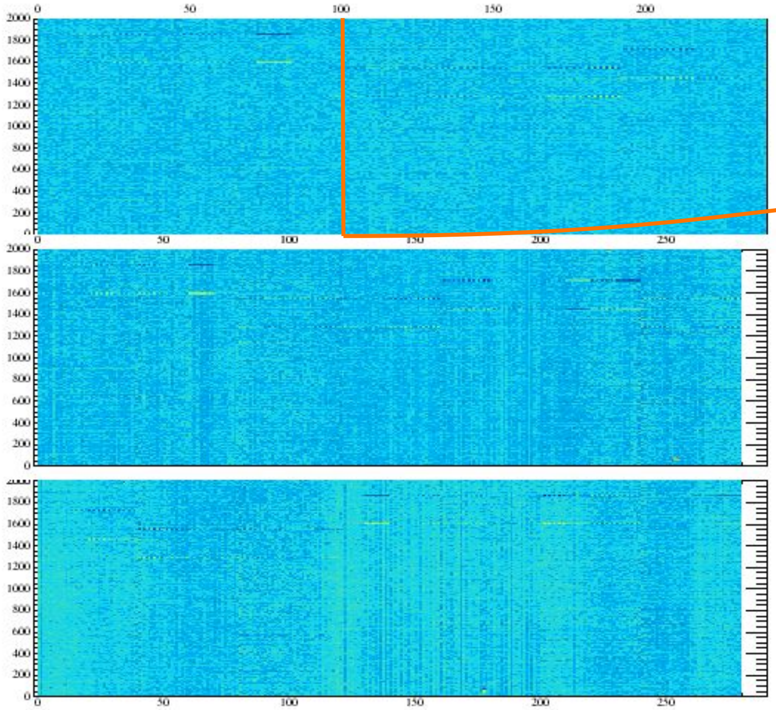
U Plane

ICEBERG data Run 13154, Event 1



Single Wire Waveform

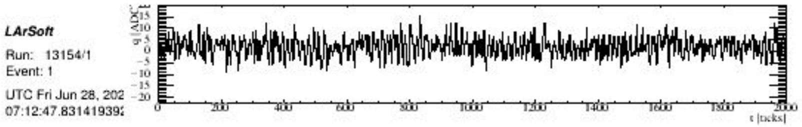
Model Noise Conditions in ICEBERG



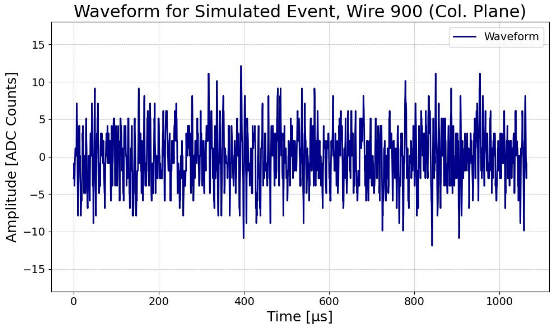
Collection Plane

V Plane

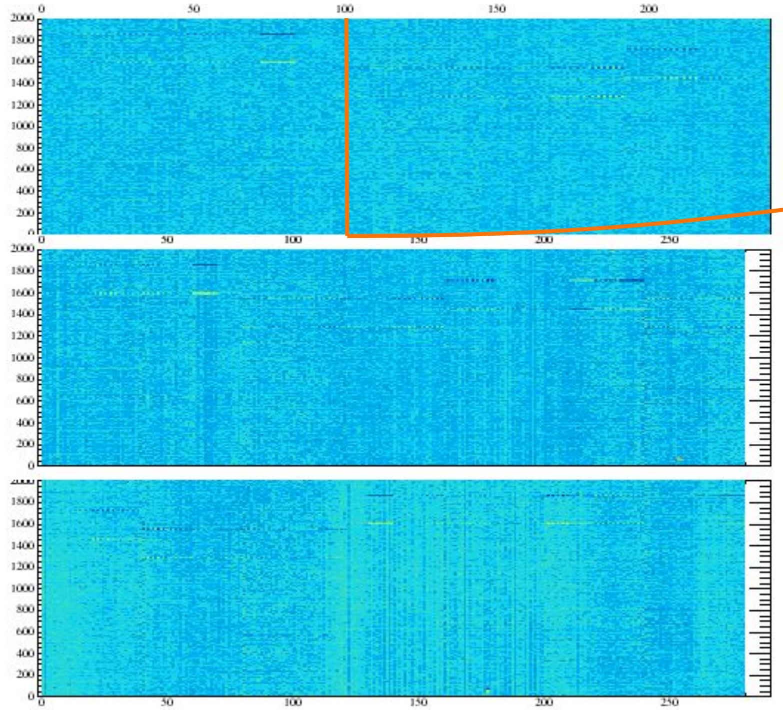
U Plane



Single Wire Waveform



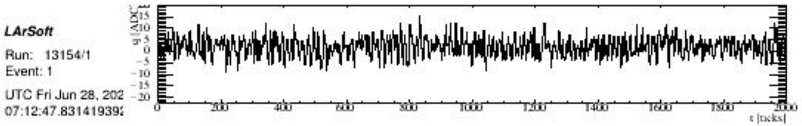
Model Noise Conditions in ICEBERG



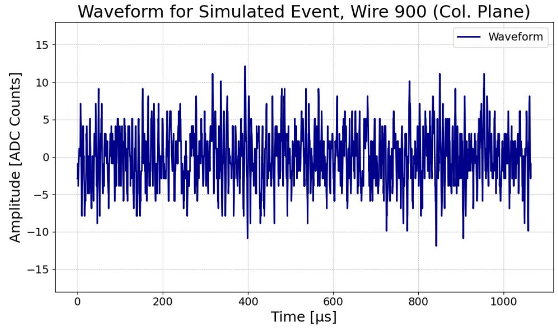
Collection Plane

V Plane

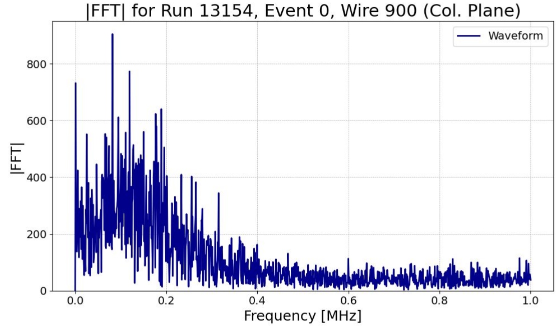
U Plane



Single Wire Waveform

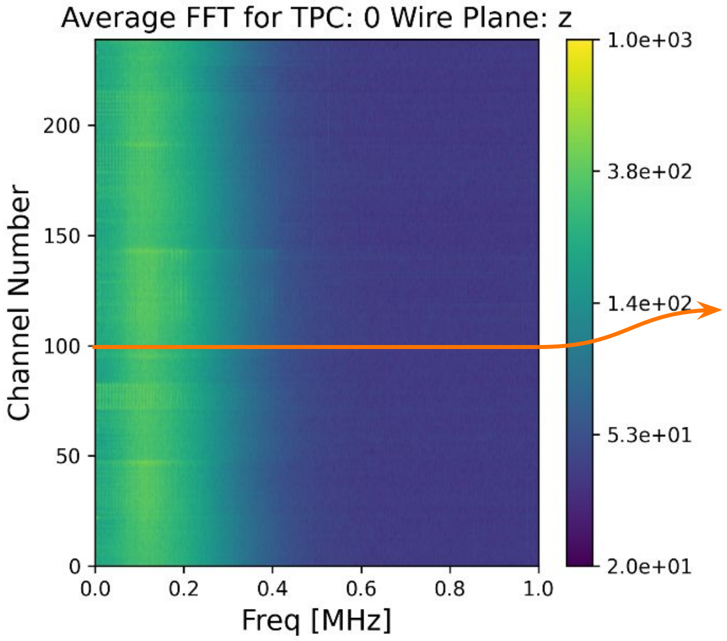


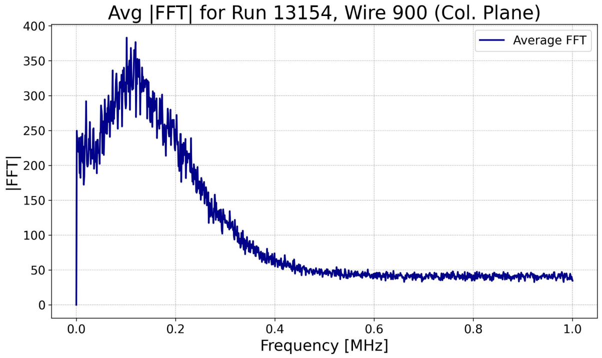
FFT



Model Noise Conditions in ICEBERG

"Incoherent Noise Model"



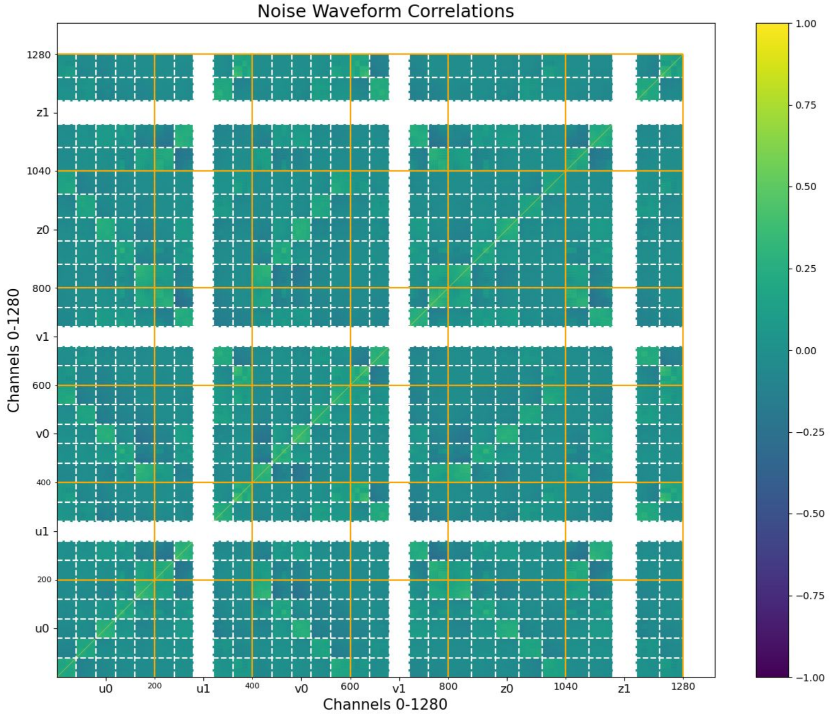


ICEBERG data
Run 13154
(48 events)

Absolute value of Fast Fourier Transform for each waveform

Averaged over all events in this run

Coherent Noise Modeling – Frequency-Dependent Correlations



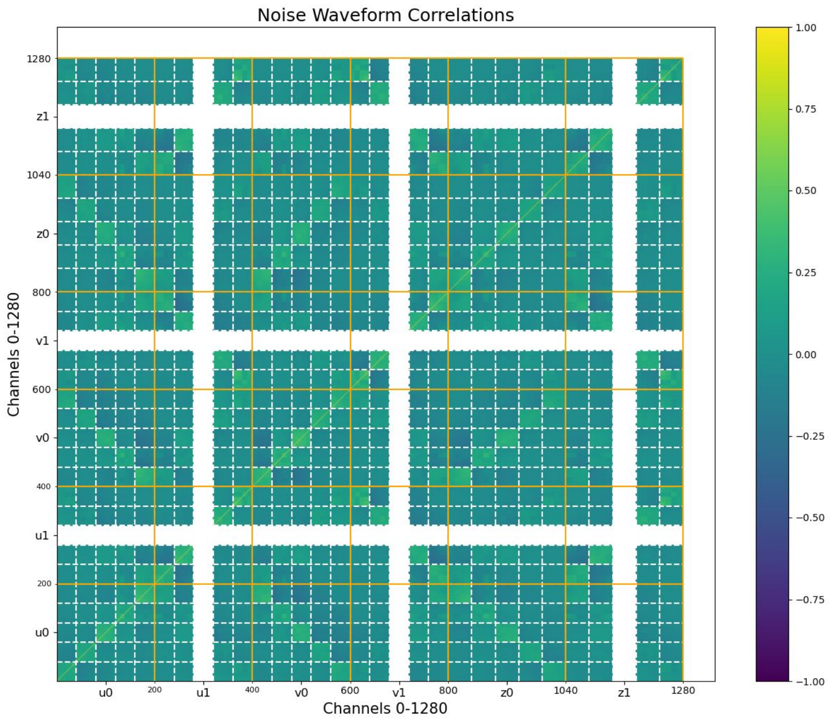
No Time Offset

Correlation matrix wire-by-wire

Time offset: 0

Frequency Mask: None

Coherent Noise Modeling – Frequency-Dependent Correlations



No Time Offset

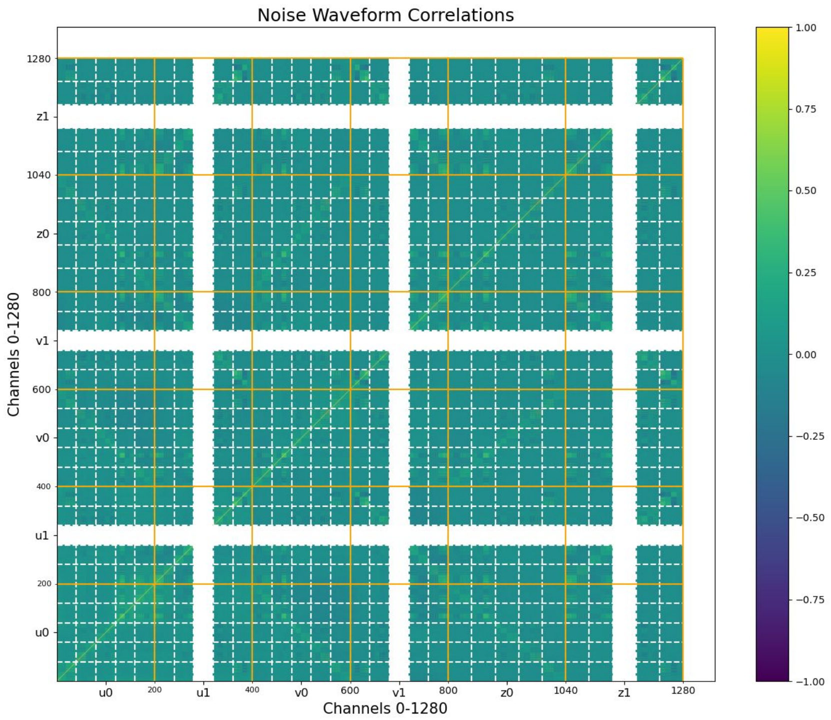
Correlation matrix wire-by-wire

Time offset: 0

Frequency Mask: None

Let's break it down further!

Coherent Noise Modeling – Frequency-Dependent Correlations



No Time Offset

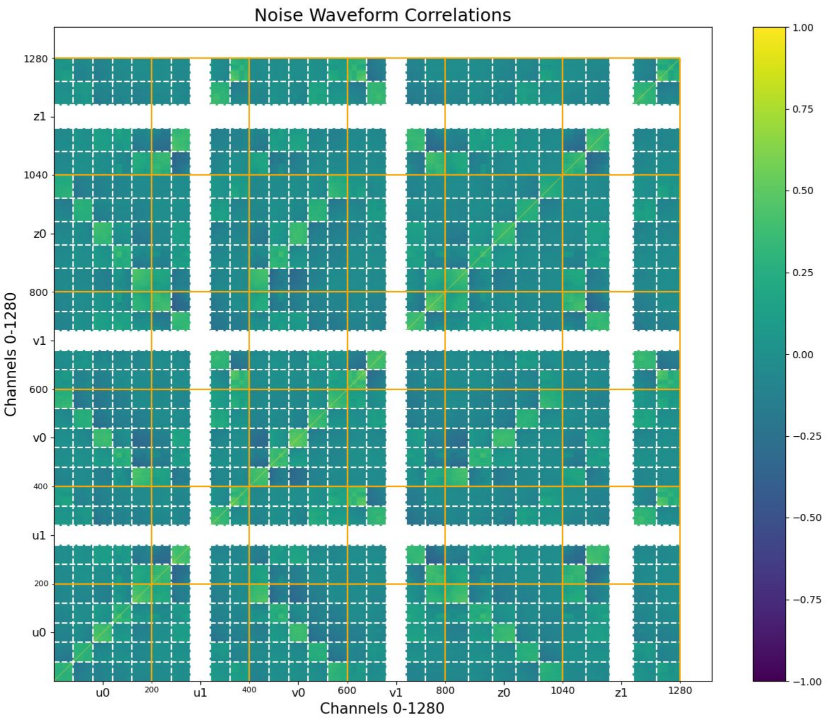
Correlation matrix wire-by-wire

Time offset: 0

Frequency Mask: 0-50 kHz

Correlations by half-FEMB

Coherent Noise Modeling – Frequency-Dependent Correlations



No Time Offset

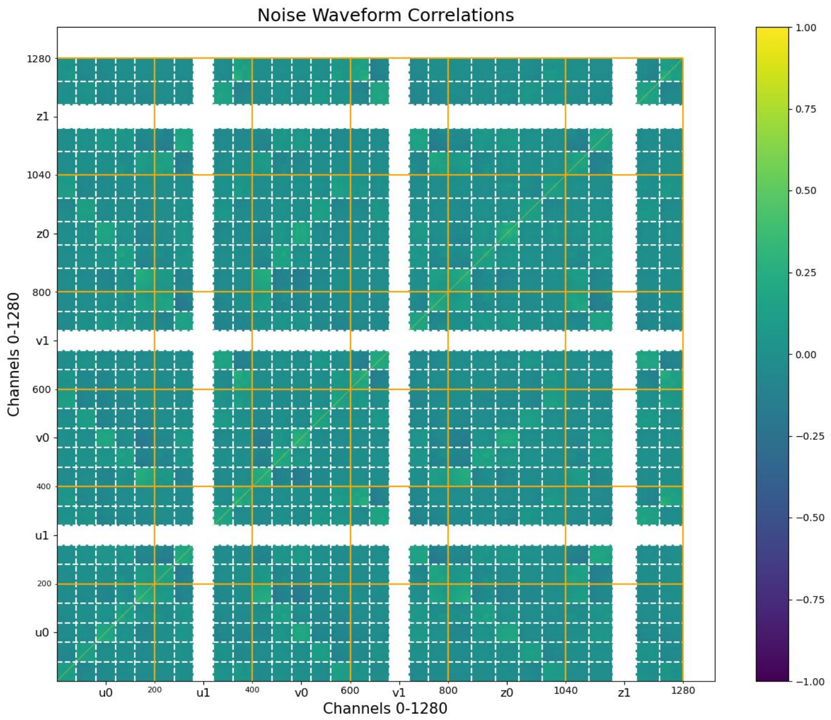
Correlation matrix wire-by-wire

Time offset: 0

Frequency Mask: 50-150 kHz

Strongest Correlations

Coherent Noise Modeling – Frequency-Dependent Correlations



No Time Offset

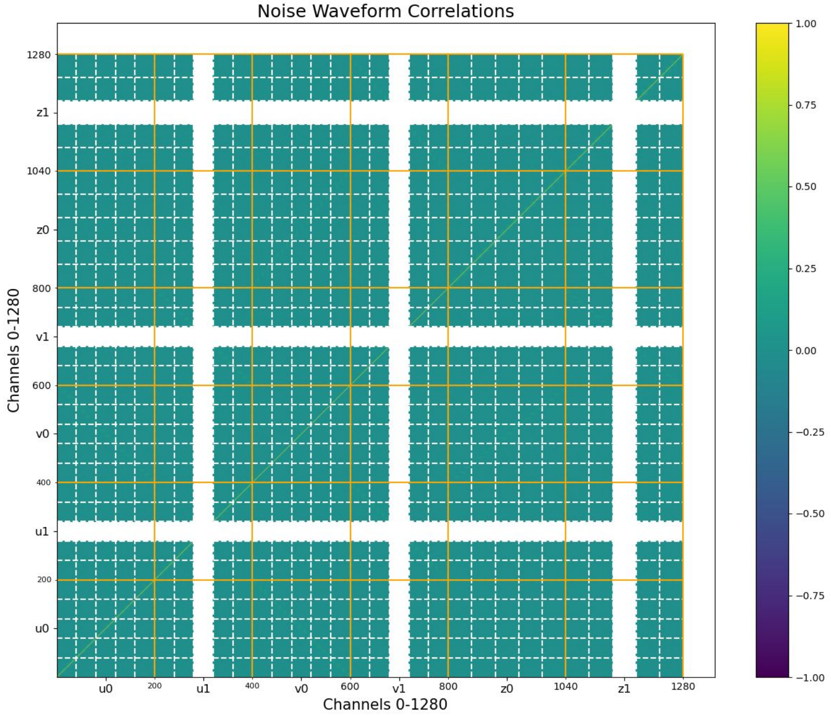
Correlation matrix wire-by-wire

Time offset: 0

Frequency Mask: 150-300 kHz

Same Shape as 50-150 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



No Time Offset

Correlation matrix wire-by-wire

Time offset: 0

Frequency Mask: 300-1000 kHz

Uncorrelated

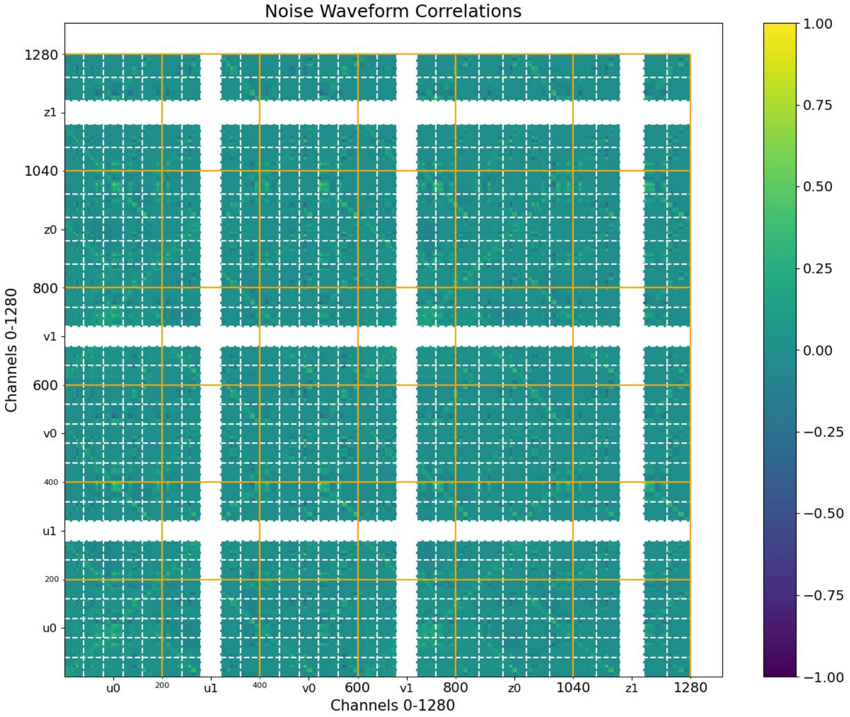
Coherent Noise Modeling – Frequency-Dependent Correlations

Looking at correlation matrices with different offsets in time between wires

$$r_{ij}(\tau) = \frac{\sum_t \left[x_i(t) - \bar{x}_i\right]\left[x_j(t+\tau) - \bar{x}_j\right]}{\sigma_i \sigma_j} \qquad -1 \leq r_{ij} \leq 1.$$

τ is our "lag", looking at τ from -3 to 3 time ticks.

Coherent Noise Modeling – Frequency-Dependent Correlations



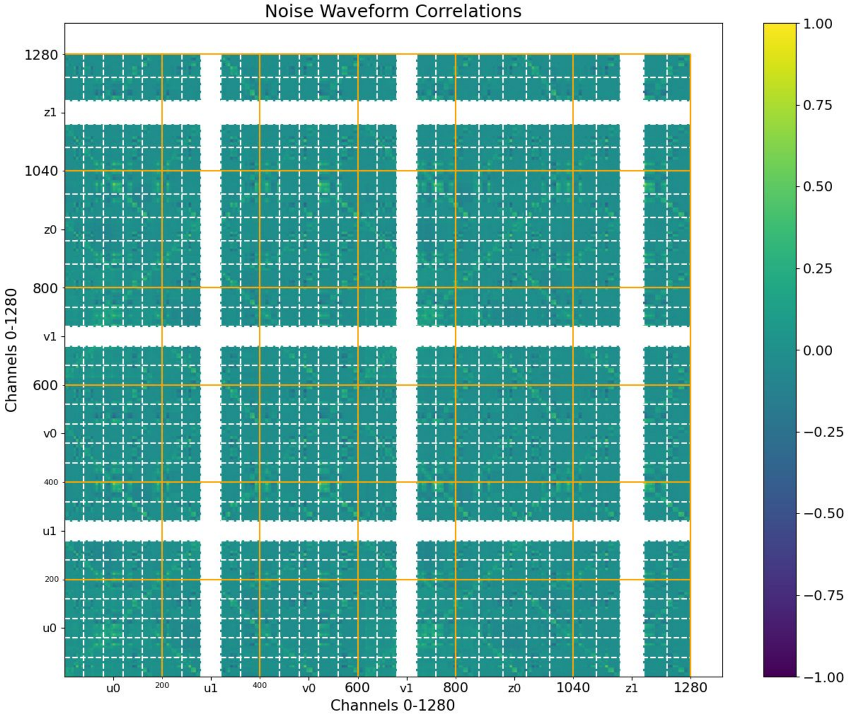
0-50 kHz Lags

Correlation matrix wire-by-wire

Time offset: -3

Frequency Mask: 0-50 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



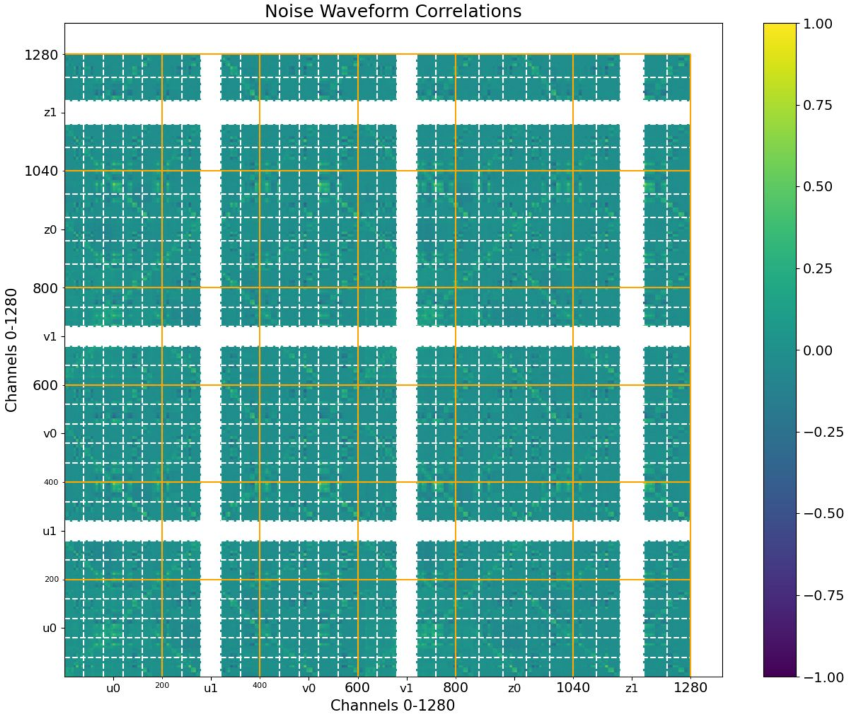
0-50 kHz Lags

Correlation matrix wire-by-wire

Time offset: -2

Frequency Mask: 0-50 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



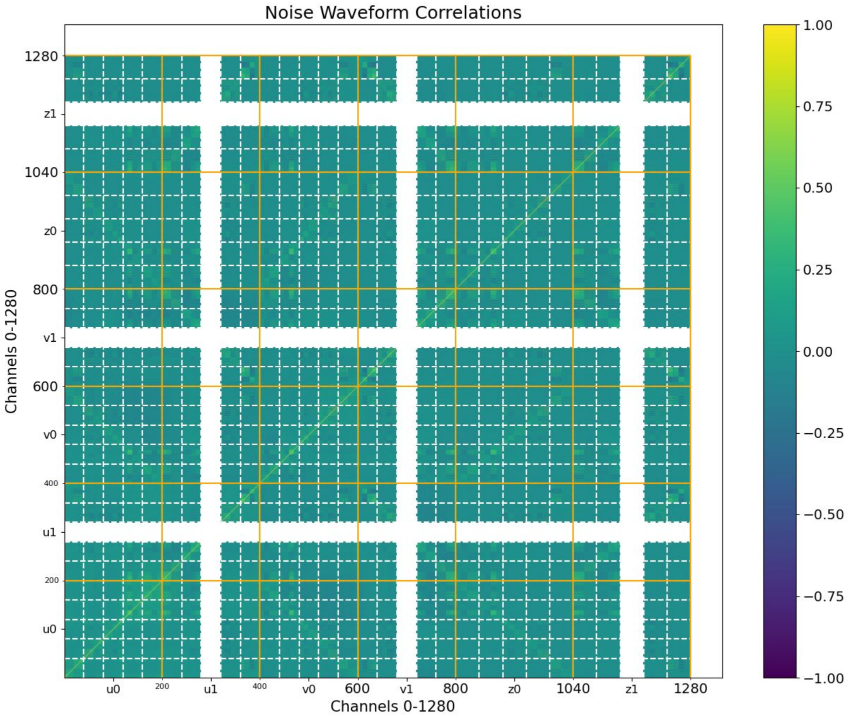
0-50 kHz Lags

Correlation matrix wire-by-wire

Time offset: -1

Frequency Mask: 0-50 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



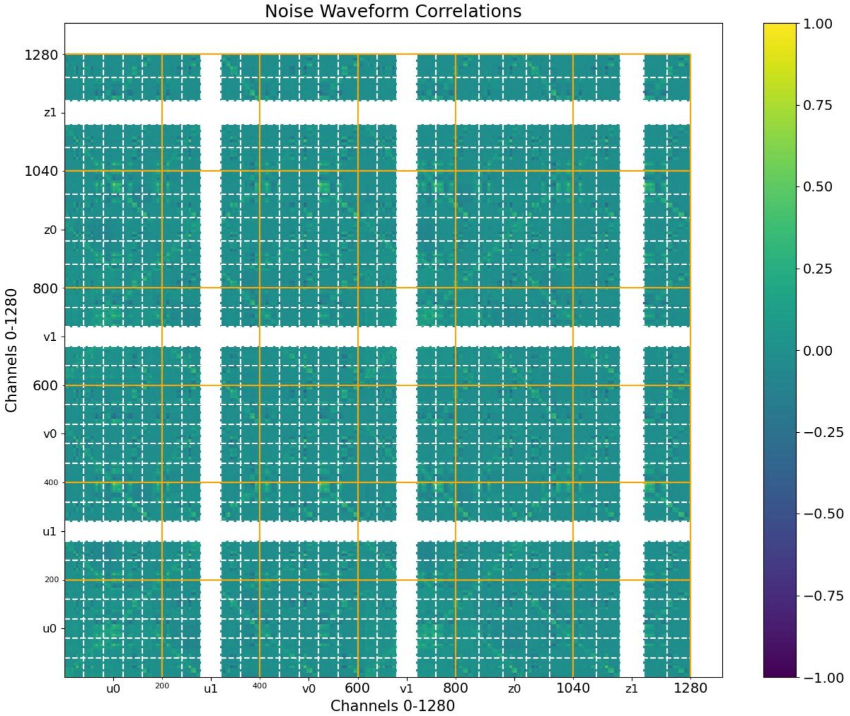
0-50 kHz Lags

Correlation matrix wire-by-wire

Time offset: 0

Frequency Mask: 0-50 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



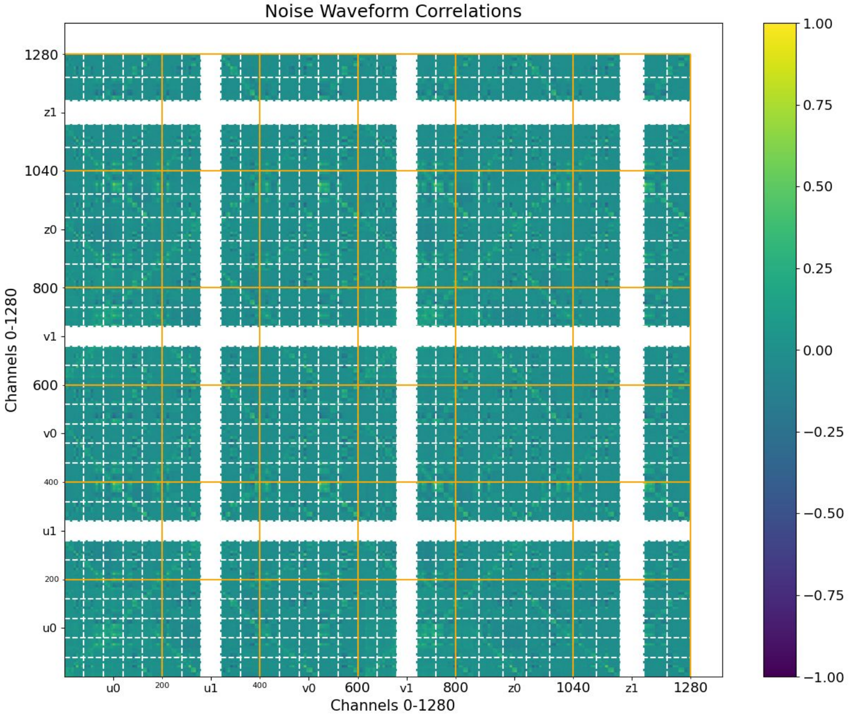
0-50 kHz Lags

Correlation matrix wire-by-wire

Time offset: +1

Frequency Mask: 0-50 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



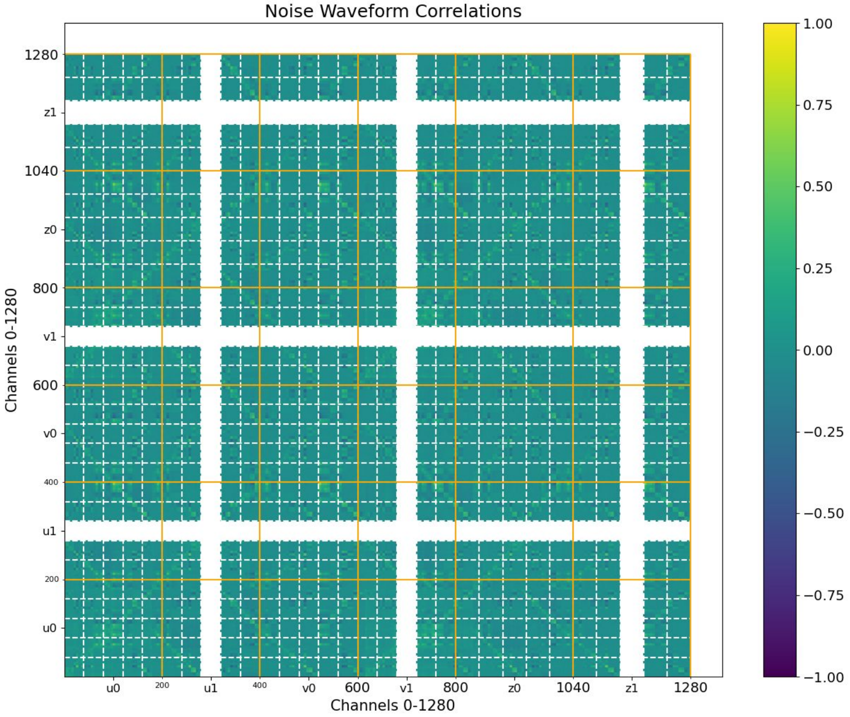
0-50 kHz Lags

Correlation matrix wire-by-wire

Time offset: +2

Frequency Mask: 0-50 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



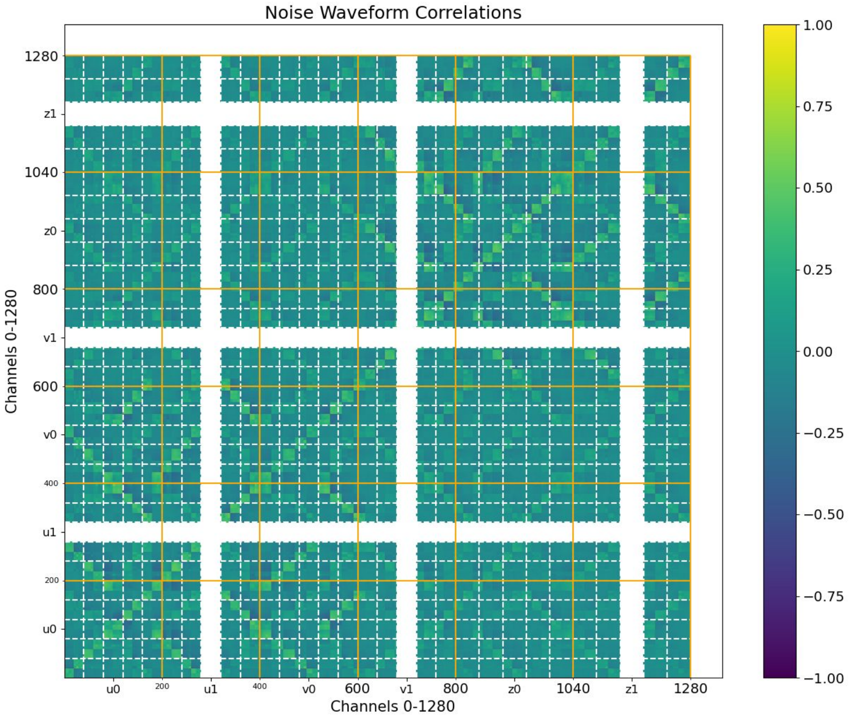
0-50 kHz Lags

Correlation matrix wire-by-wire

Time offset: +3

Frequency Mask: 0-50 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



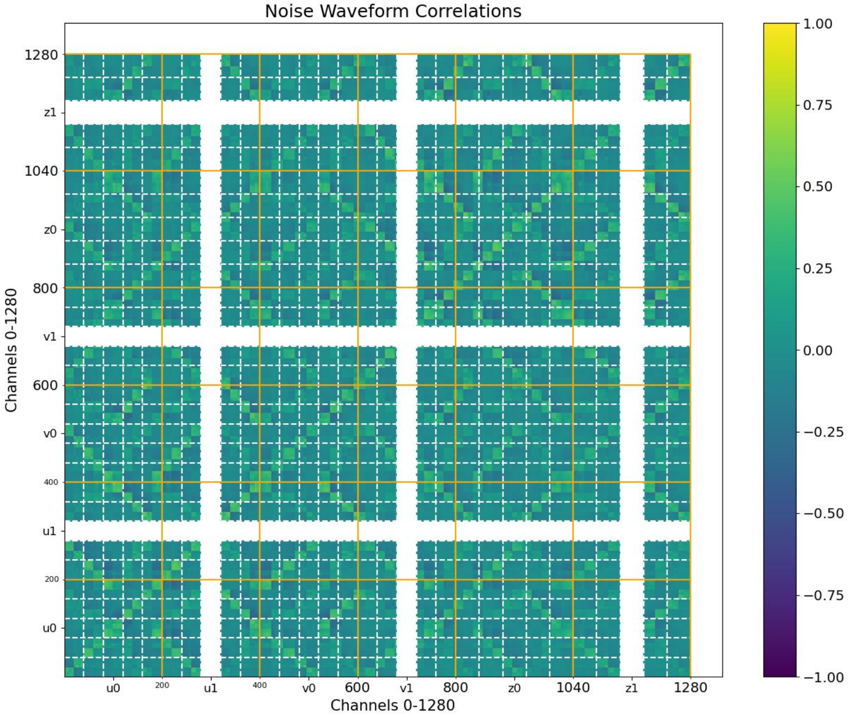
50-150 kHz Lags

Correlation matrix wire-by-wire

Time offset: -3

Frequency Mask: 50-150 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



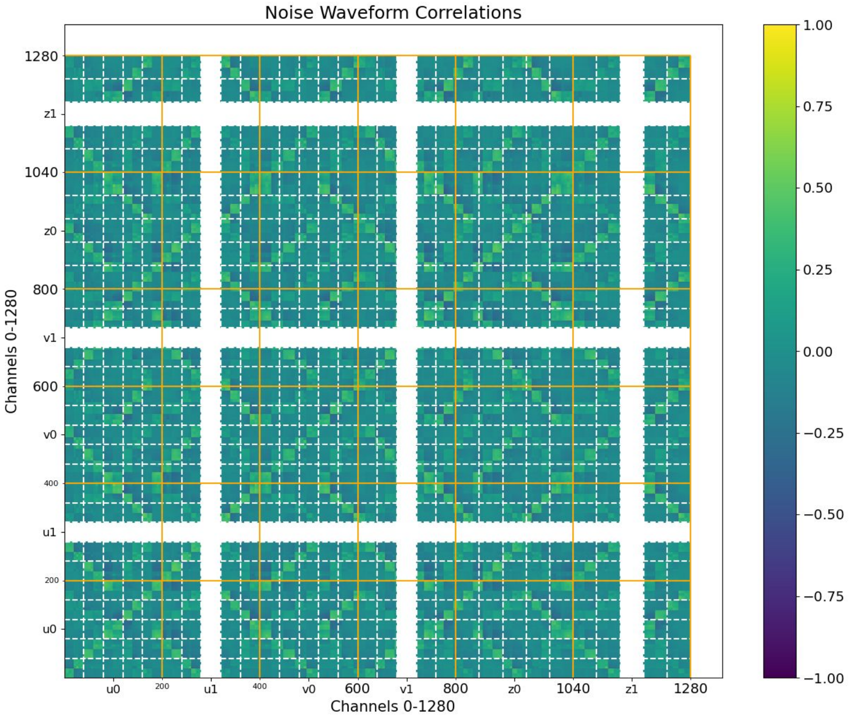
50-150 kHz Lags

Correlation matrix wire-by-wire

Time offset: -2

Frequency Mask: 50-150 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



50-150 kHz Lags

Correlation matrix wire-by-wire

Time offset: -1

Frequency Mask: 50-150 kHz

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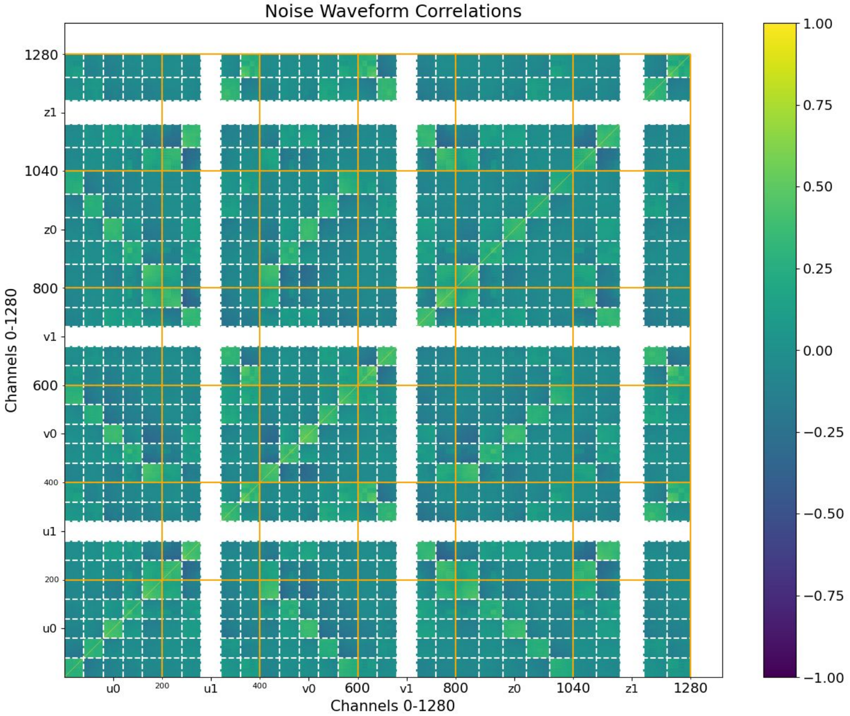

50-150 kHz Lags

Correlation matrix wire-by-wire

Time offset: 0

Frequency Mask: 50-150 kHz

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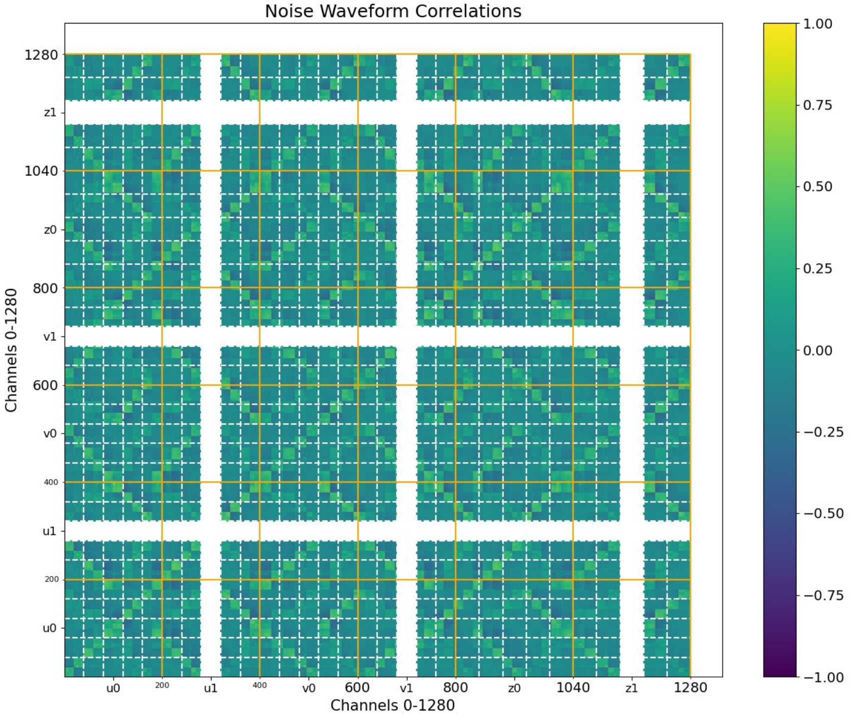


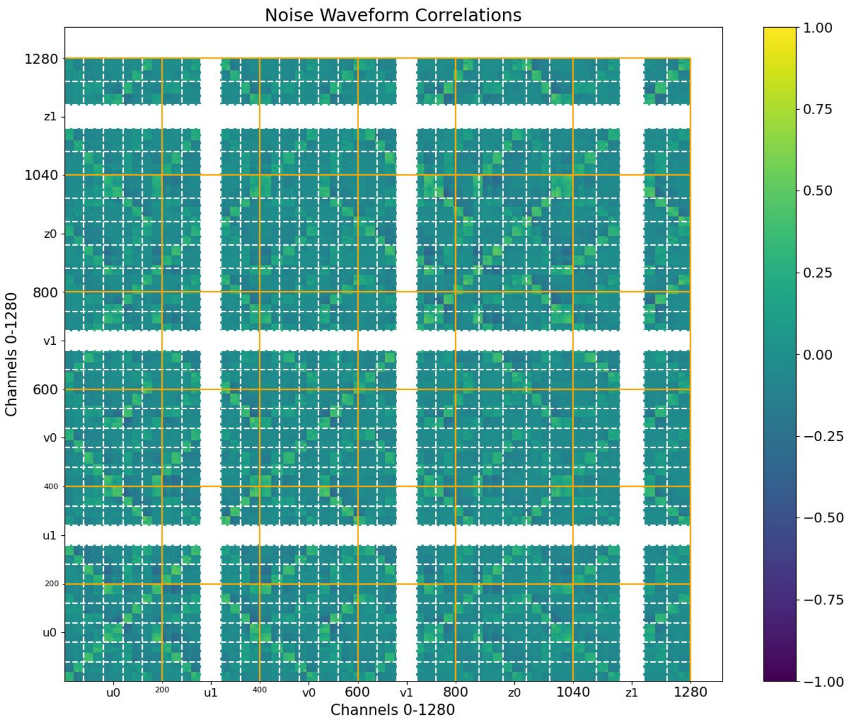
50-150 kHz Lags

Correlation matrix wire-by-wire

Time offset: +1

Frequency Mask: 50-150 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations

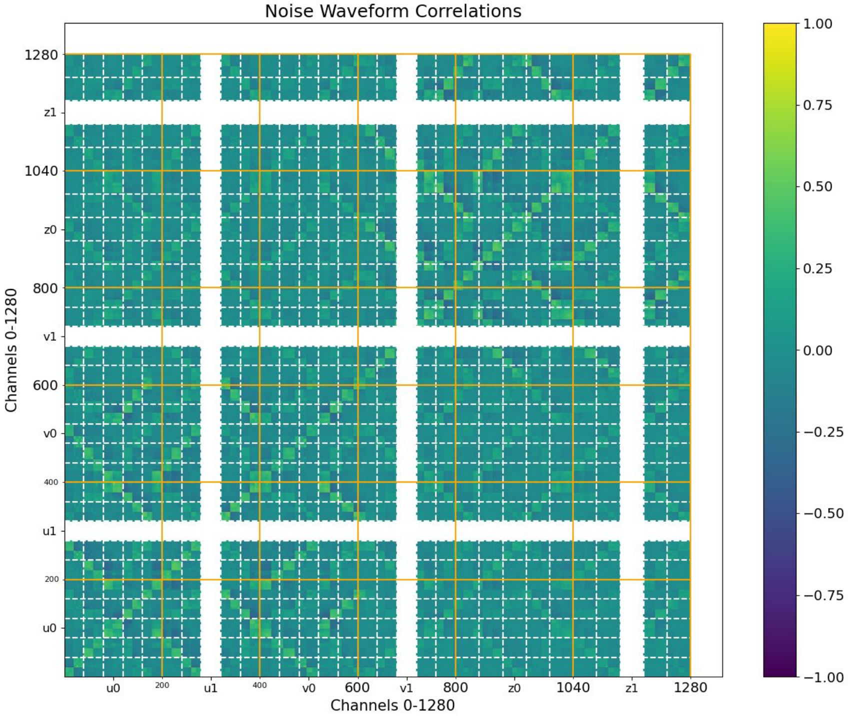


50-150 kHz Lags

Correlation matrix wire-by-wire

Time offset: +2
Frequency Mask: 50-150 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



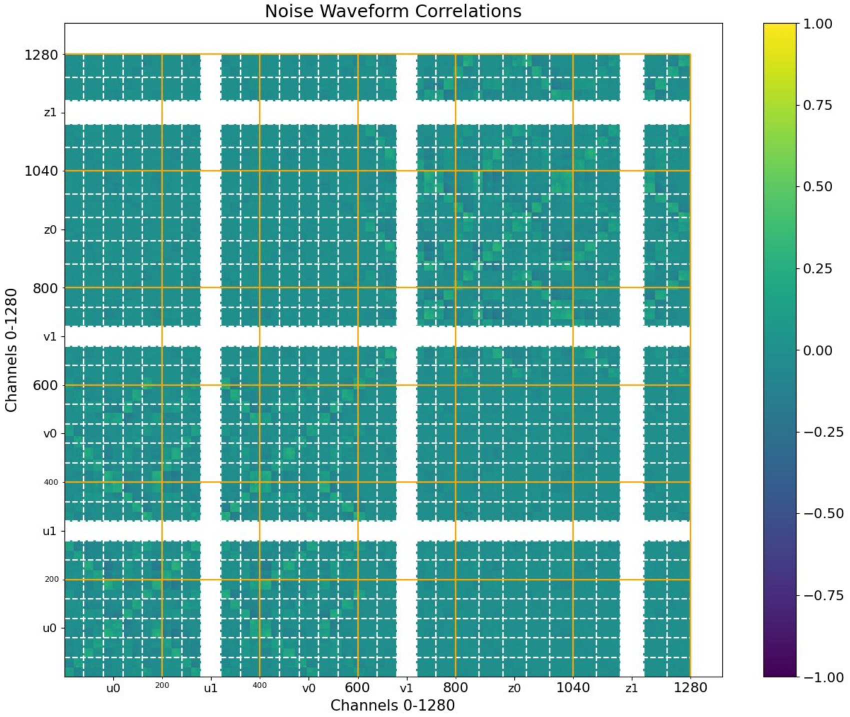
50-150 kHz Lags

Correlation matrix wire-by-wire

Time offset: +3

Frequency Mask: 50-150 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



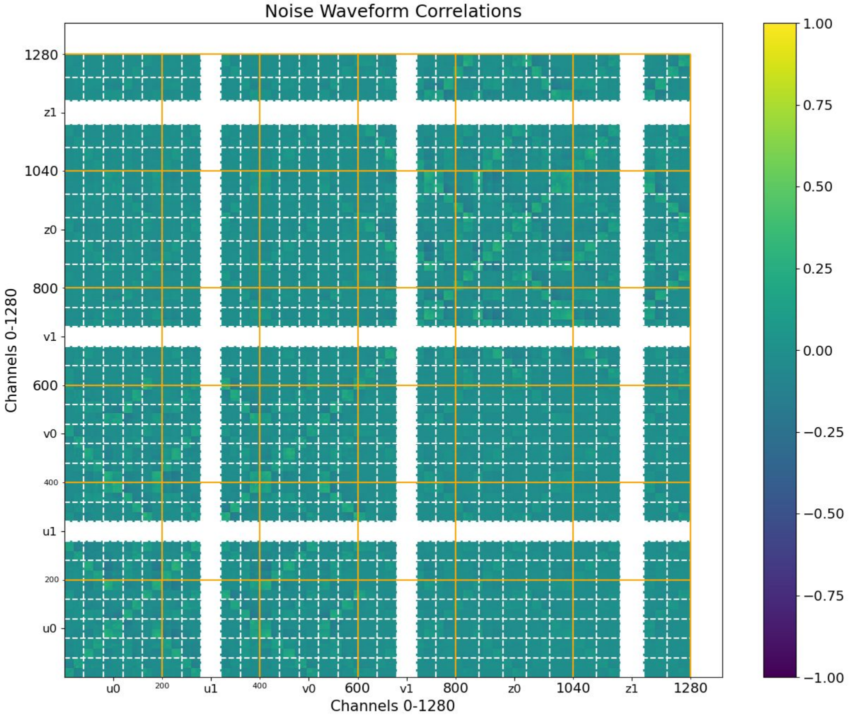
150-300 kHz Lags

Correlation matrix wire-by-wire

Time offset: -3

Frequency Mask: 150-300 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



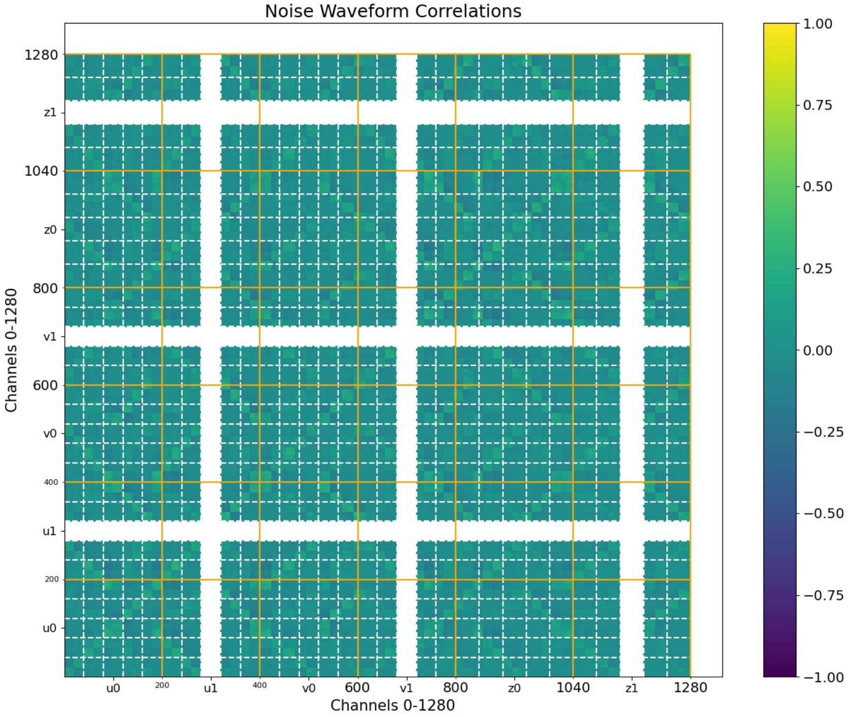
150-300 kHz Lags

Correlation matrix wire-by-wire

Time offset: -2

Frequency Mask: 150-300 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



150-300 kHz Lags

Correlation matrix wire-by-wire

Time offset: -1

Frequency Mask: 150-300 kHz

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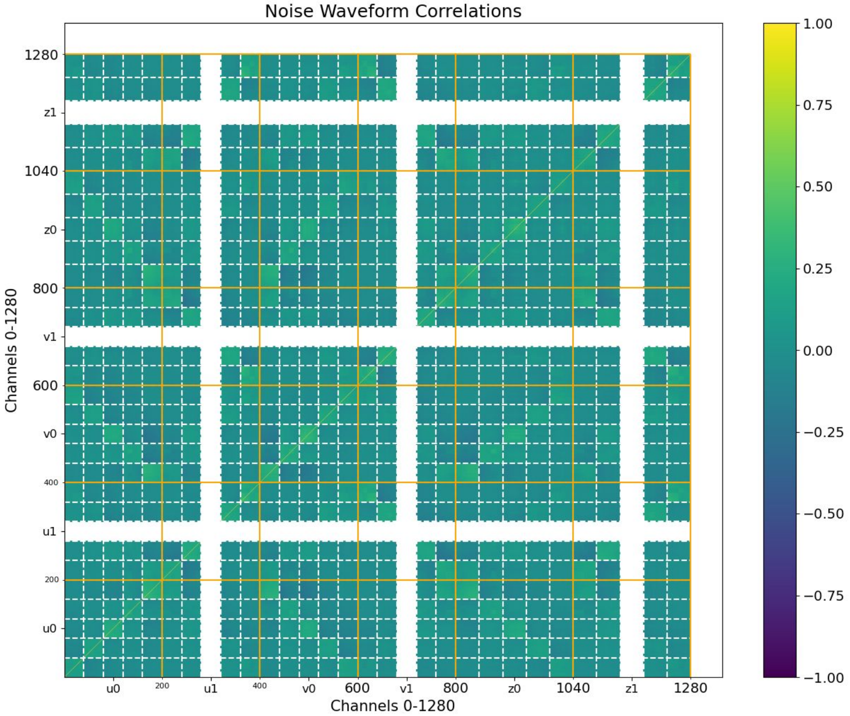


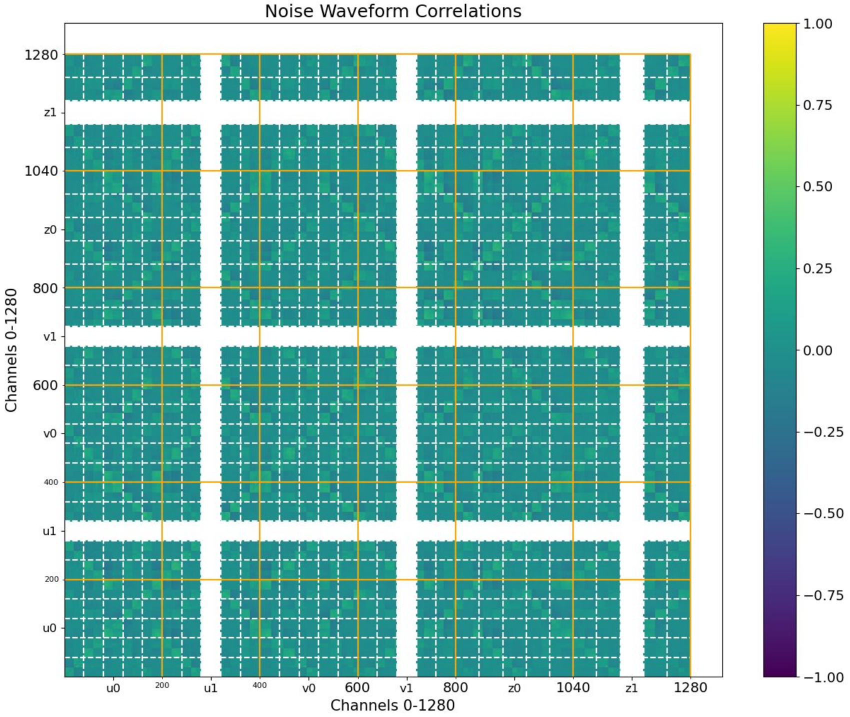
150-300 kHz Lags

Correlation matrix wire-by-wire

Time offset: 0

Frequency Mask: 150-300 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations

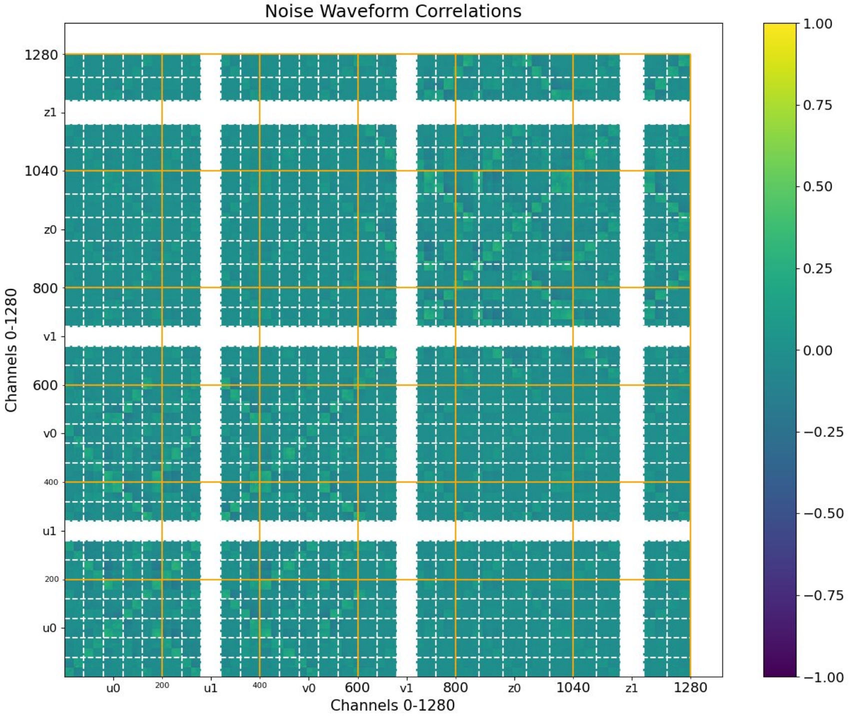


150-300 kHz Lags

Correlation matrix wire-by-wire

Time offset: +1
Frequency Mask: 150-300 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



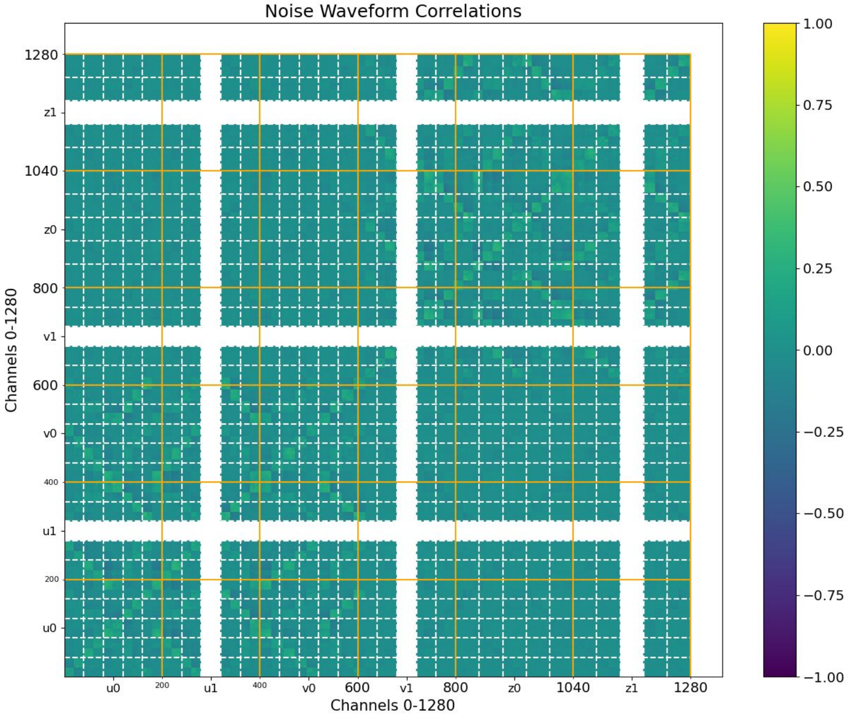
150-300 kHz Lags

Correlation matrix wire-by-wire

Time offset: +2

Frequency Mask: 150-300 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



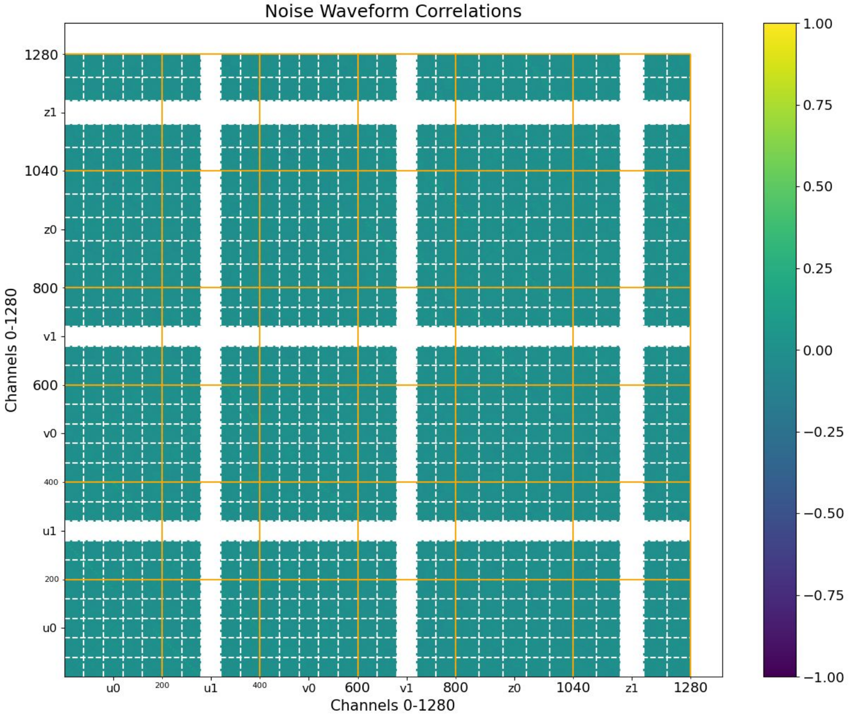
150-300 kHz Lags

Correlation matrix wire-by-wire

Time offset: +3

Frequency Mask: 150-300 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



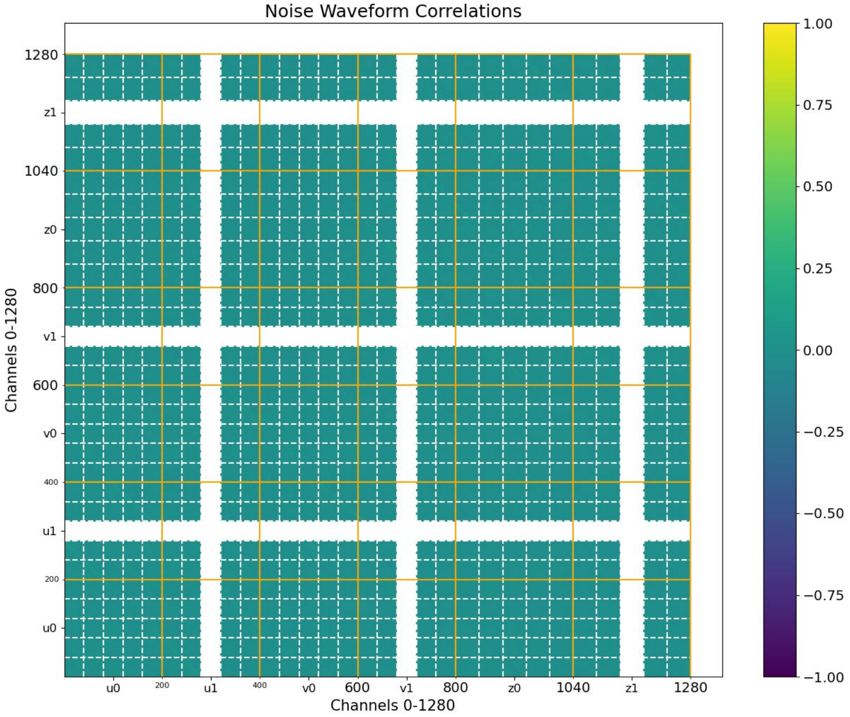
300-1000 kHz Lags

Correlation matrix wire-by-wire

Time offset: -3

Frequency Mask: 300-1000 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



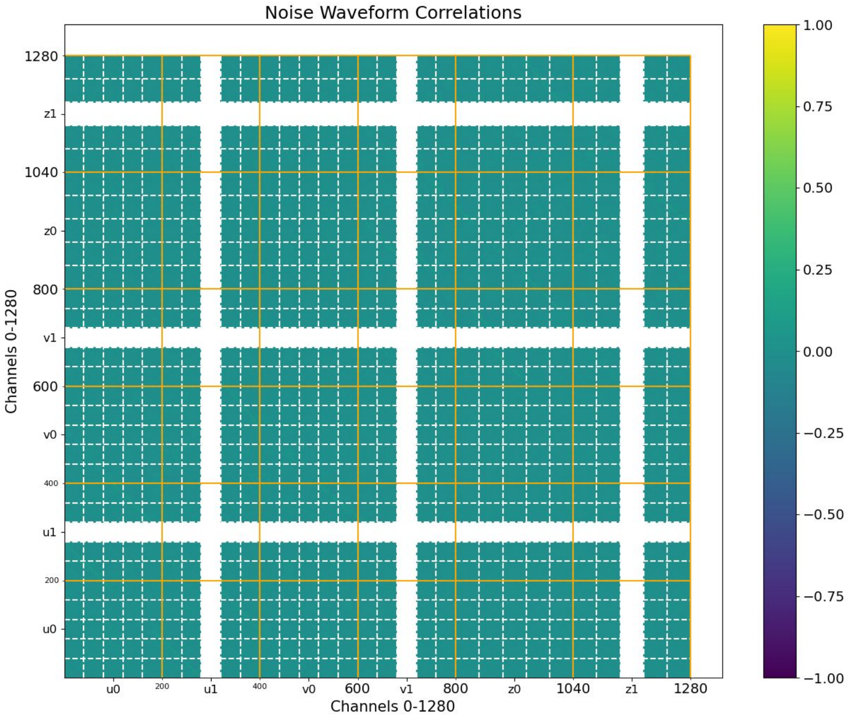
300-1000 kHz Lags

Correlation matrix wire-by-wire

Time offset: -2

Frequency Mask: 300-1000 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



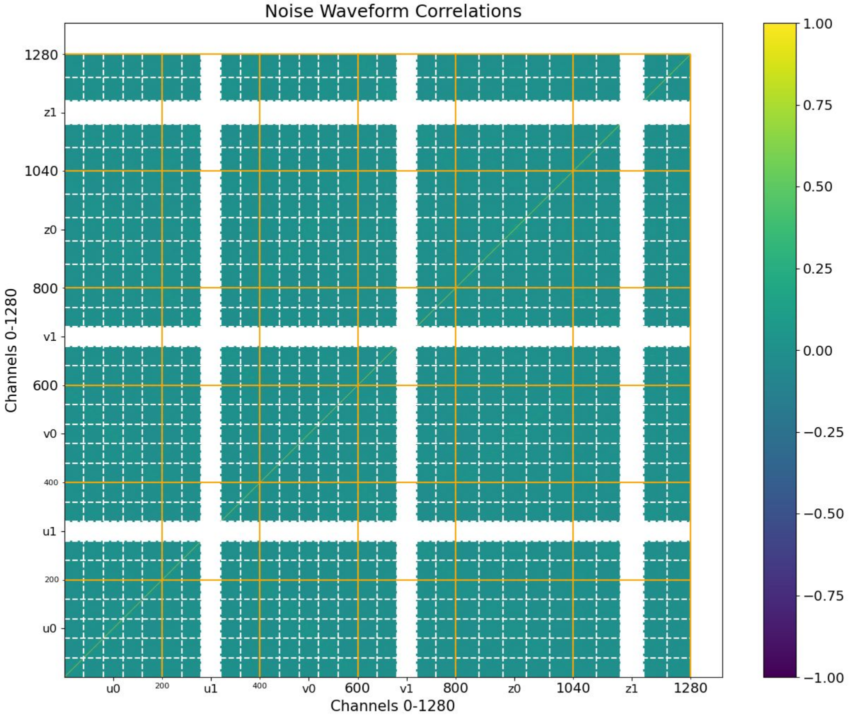
300-1000 kHz Lags

Correlation matrix wire-by-wire

Time offset: -1

Frequency Mask: 300-1000 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



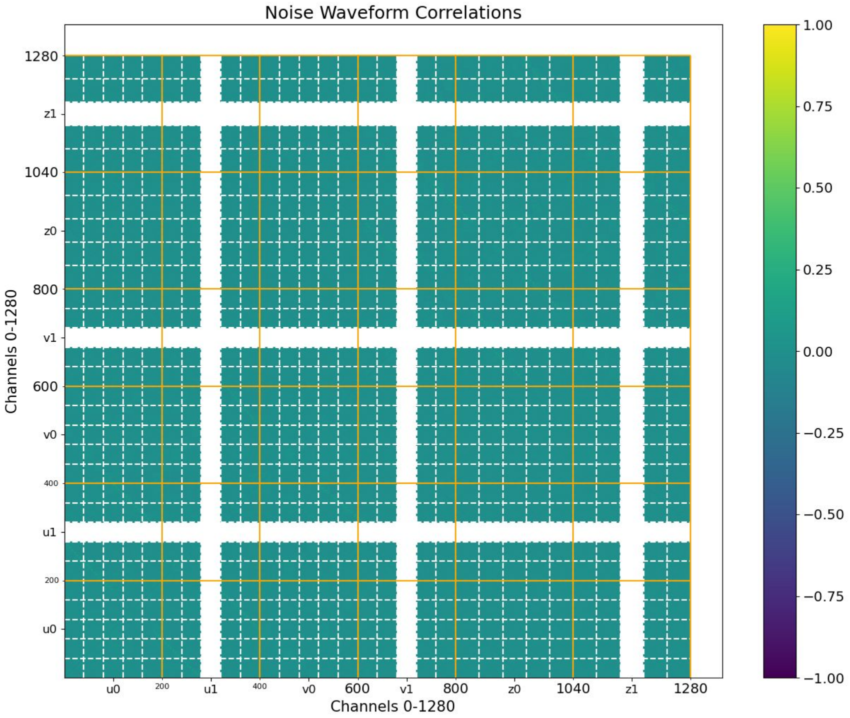
300-1000 kHz Lags

Correlation matrix wire-by-wire

Time offset: 0

Frequency Mask: 300-1000 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



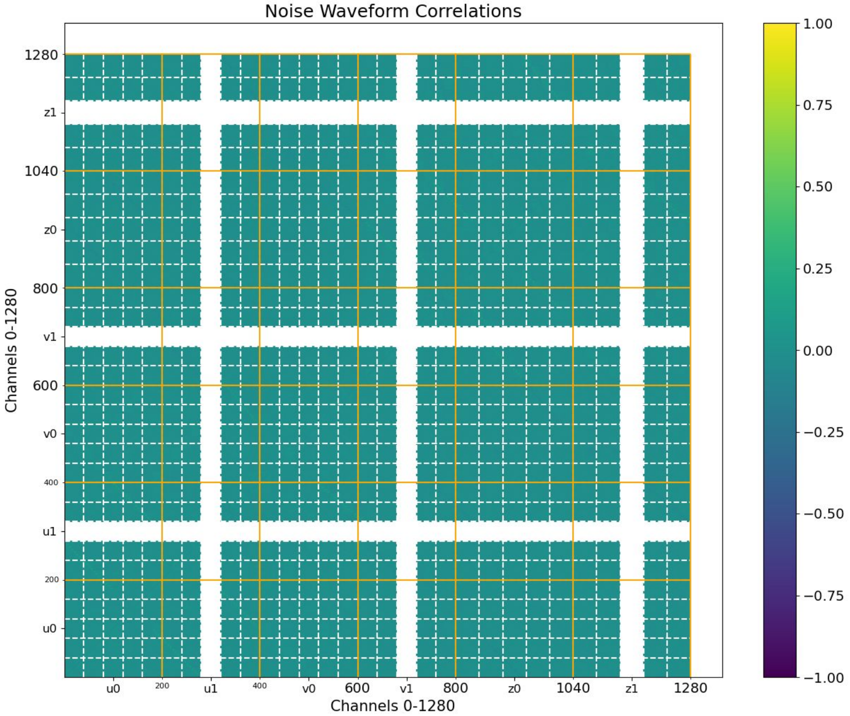
300-1000 kHz Lags

Correlation matrix wire-by-wire

Time offset: +1

Frequency Mask: 300-1000 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



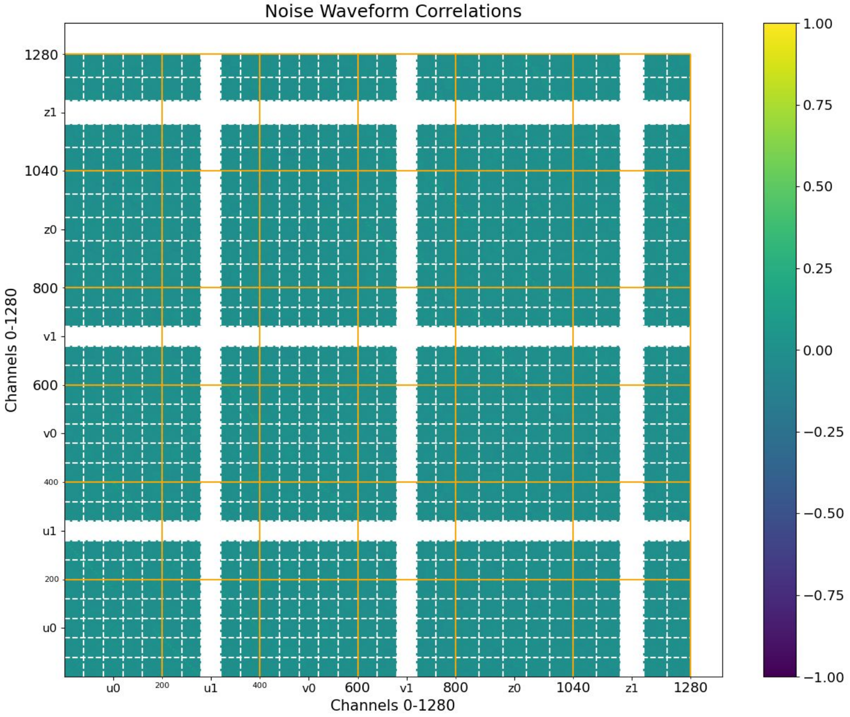
300-1000 kHz Lags

Correlation matrix wire-by-wire

Time offset: +2

Frequency Mask: 300-1000 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations



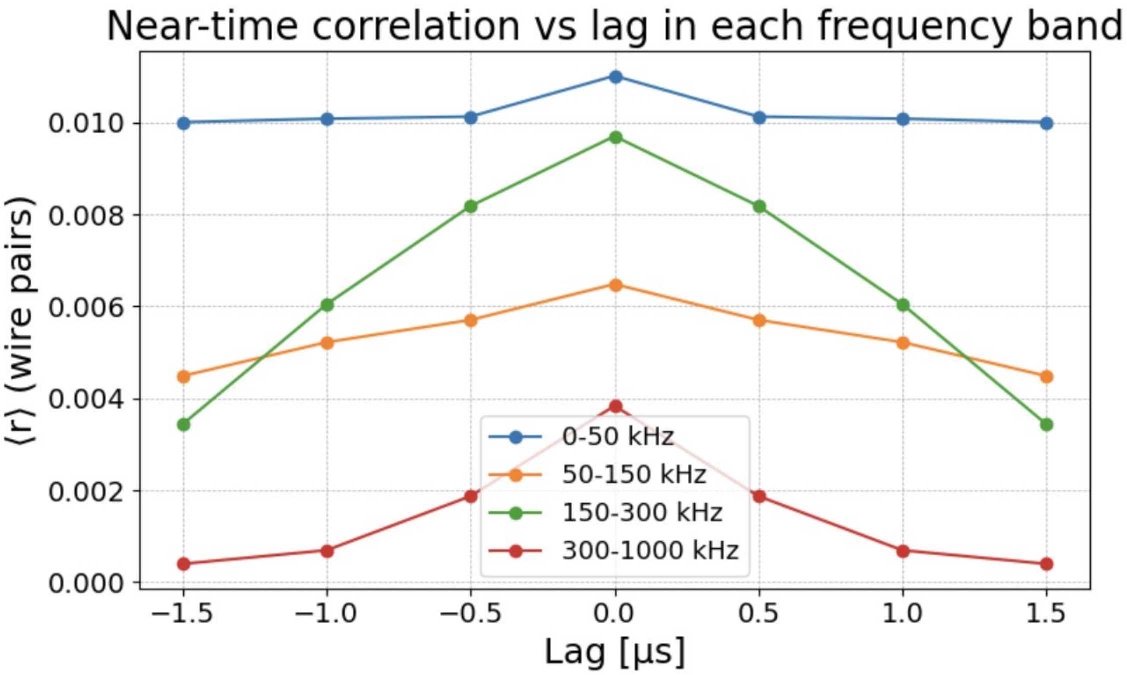
300-1000 kHz Lags

Correlation matrix wire-by-wire

Time offset: +3

Frequency Mask: 300-1000 kHz

Coherent Noise Modeling – Frequency-Dependent Correlations

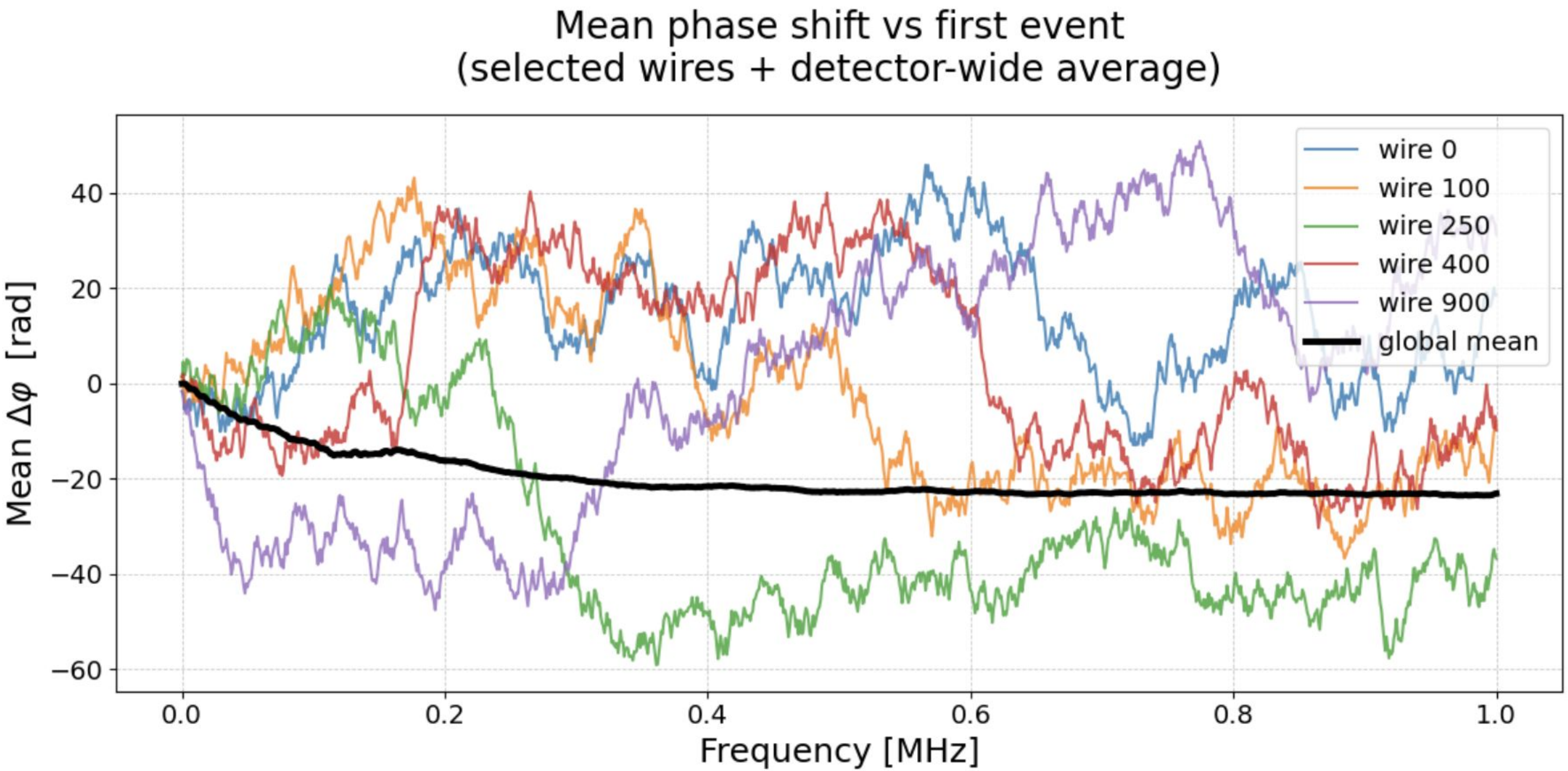


$$r_{ij}(\tau) = \frac{\sum_t \left[x_i(t) - \bar{x}_i\right]\left[x_j(t+\tau) - \bar{x}_j\right]}{\sigma_i \sigma_j}$$

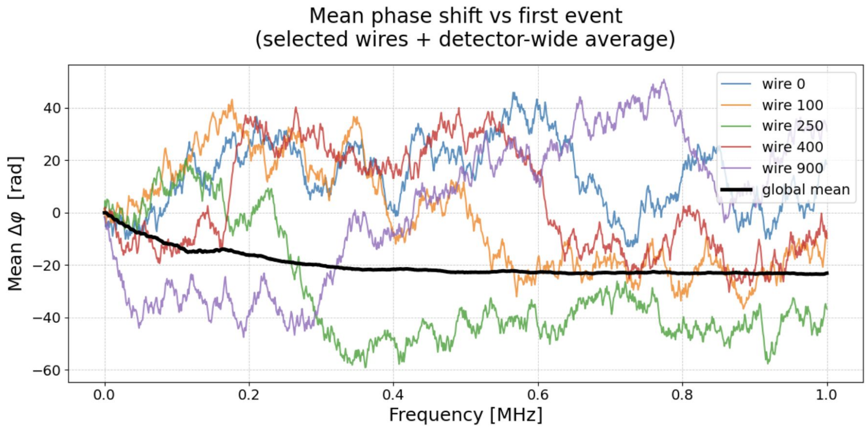
$$-1 \leq r_{ij} \leq 1.$$

$$\langle r \rangle(\tau) = \frac{1}{N_{\text{pairs}}} \sum_{i<j} r_{ij}(\tau)$$

Coherent Noise Modeling – Phase Difference



Coherent Noise Modeling – Phase Difference



How synchronous the coherent noise really is across wires and over time?

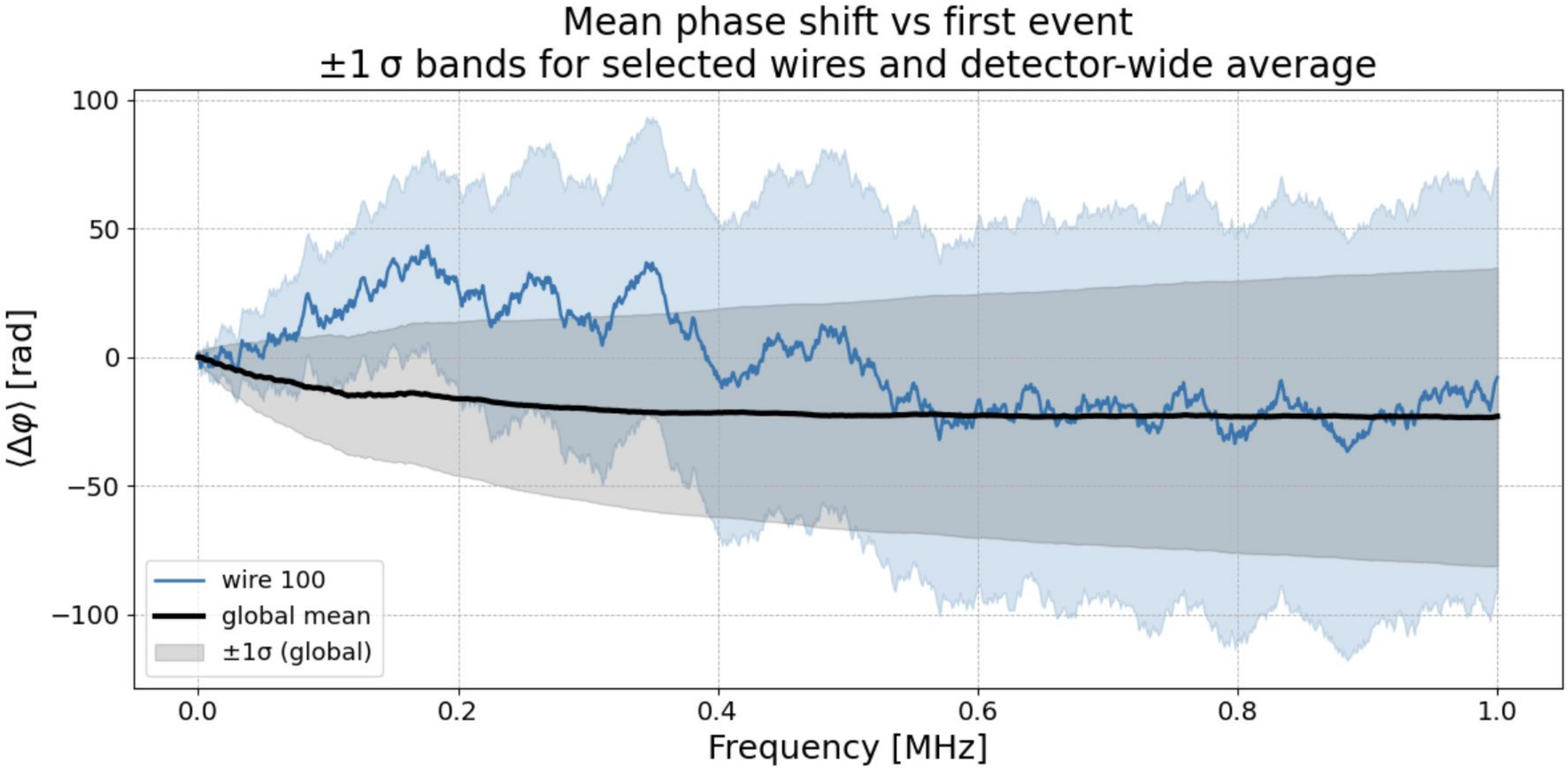
- If all curves were flat and overlapping, one common waveform with no per-wire phase is sufficient.

$$\Delta t = \frac{\Delta\varphi}{2\pi f}.$$

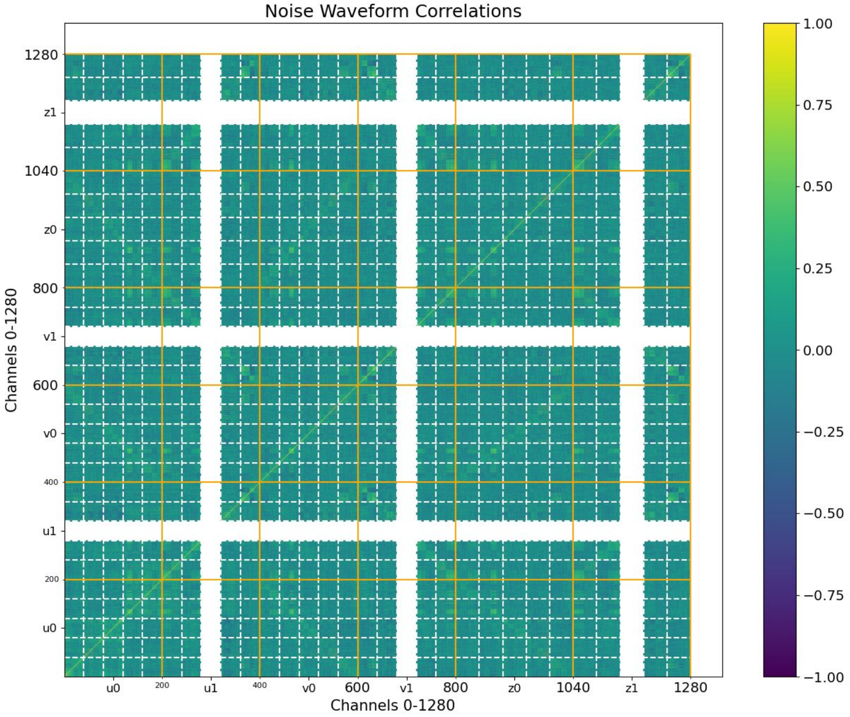
- Because they diverge by tens of radians, we should add
  1. a static delay per wire or per ASIC, and
  2. a small random phase jitter each event

3. No global time offset required

Coherent Noise Modeling – Phase Difference

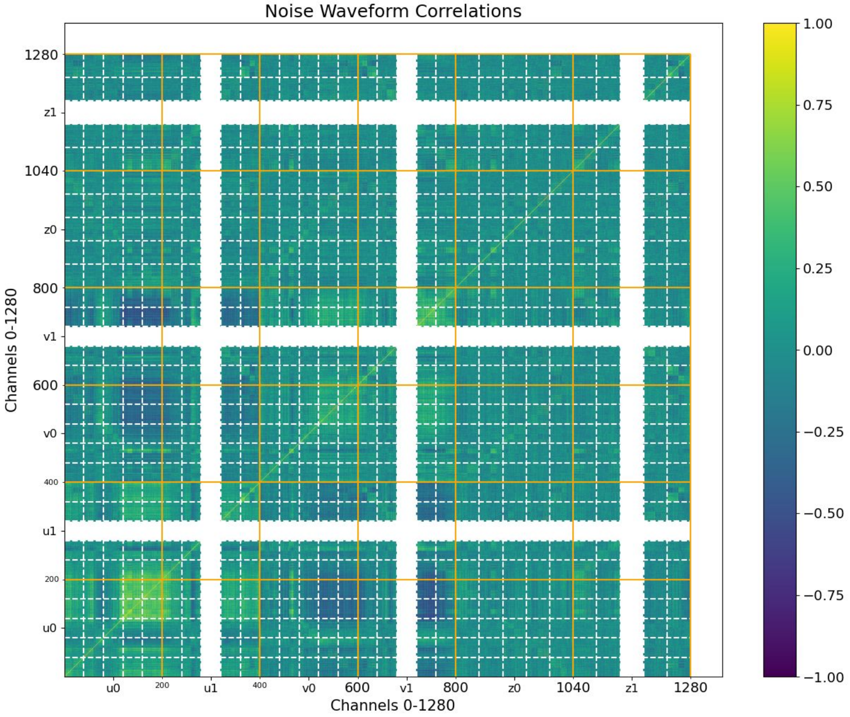


Coherent Noise Modeling – Transient Noise



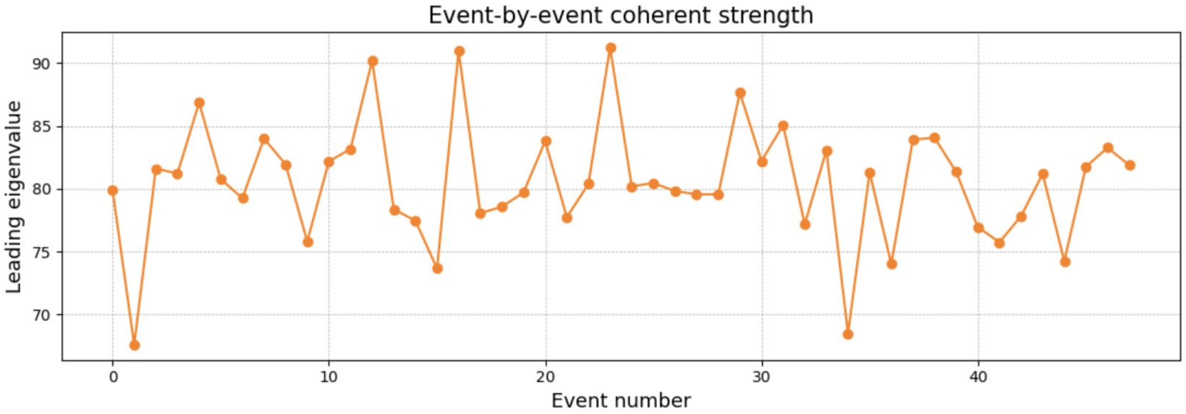
0-50 kHz
Event 0

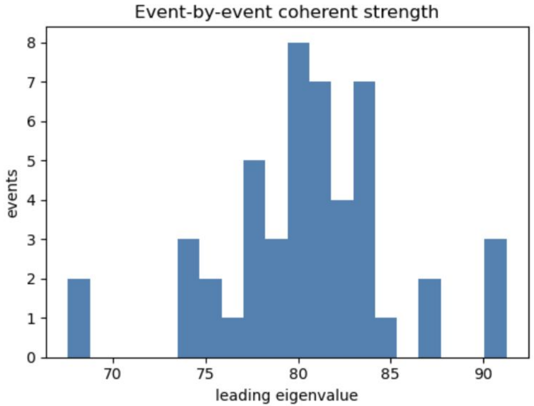
Coherent Noise Modeling – Transient Noise

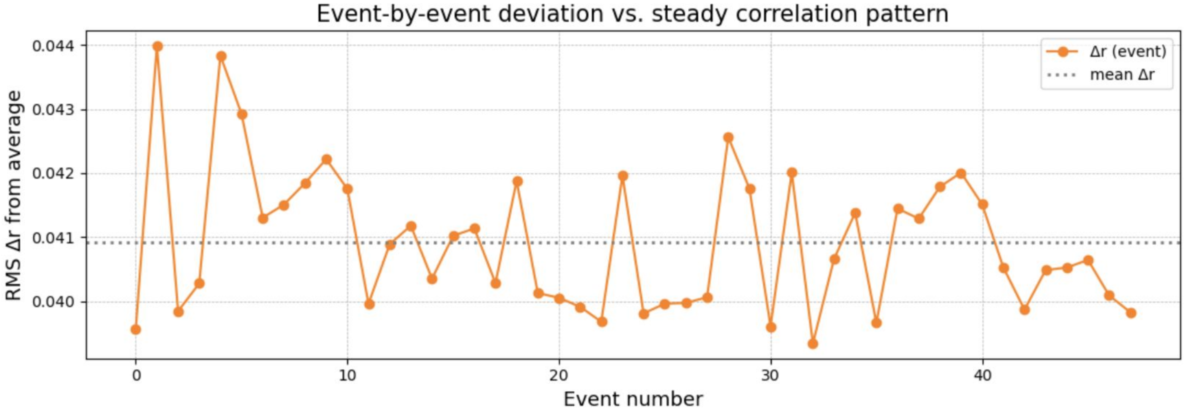


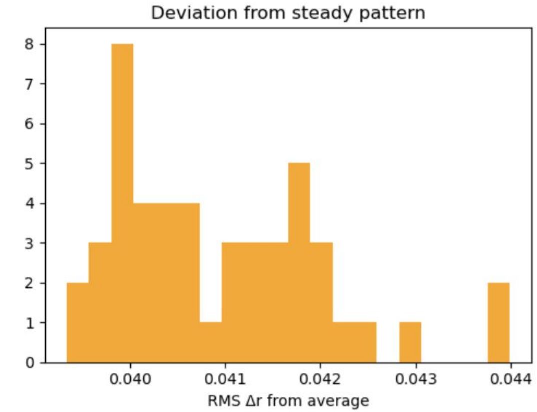
0-50 kHz
Event 2

Coherent Noise Modeling – Transient Noise

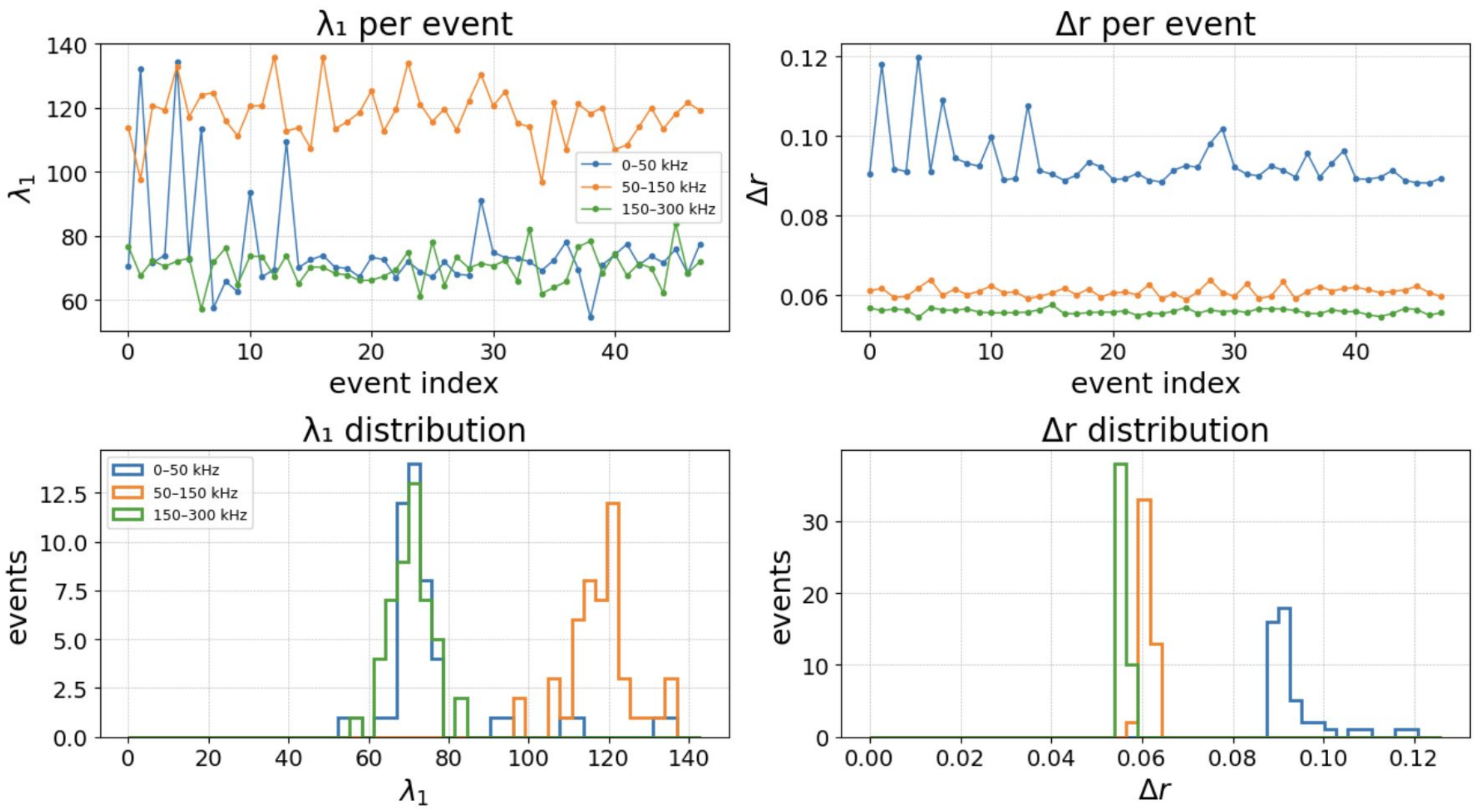






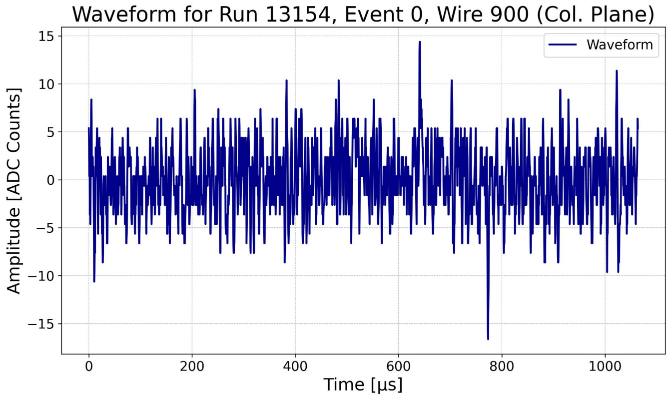


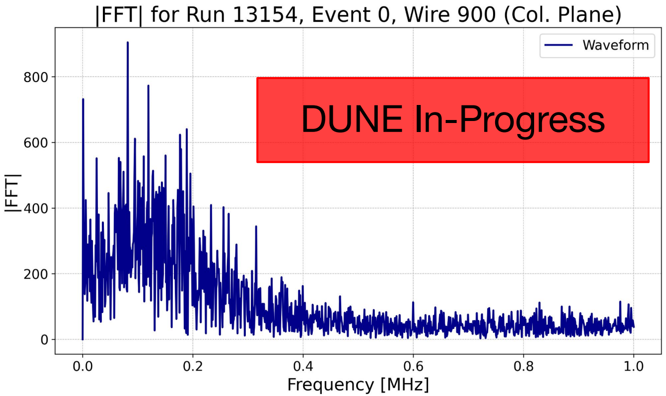
Coherent Noise Modeling – Transient Noise



Simulate Noise

ICEBERG Data





1D Incoherent Simulation – no time-correlations

$$f(t) = \sum_{n=1}^{N} q_n \cdot i(t - t_n)$$

Amplitude

Noise pulse

$$F(\omega) = \sum_{n=1}^{N} |I(\omega)| \cdot e^{-j\theta_n(\omega)}$$

|FFT| of pulse

Uniform phase

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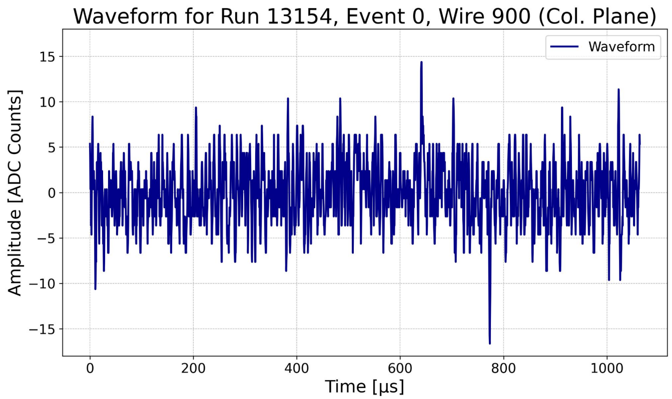
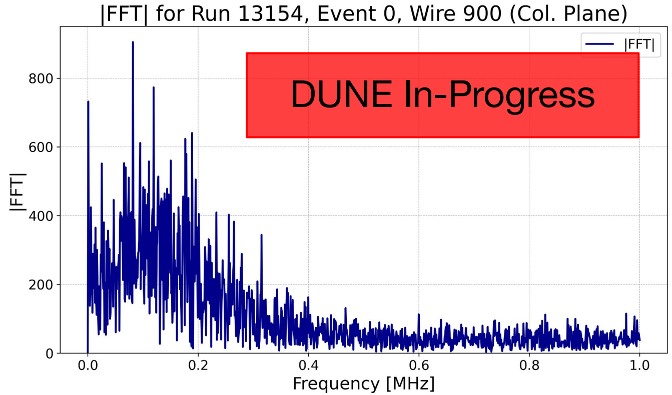
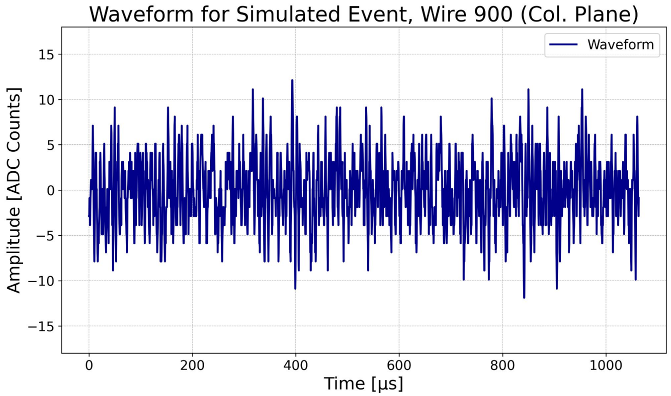
Simulate Noise

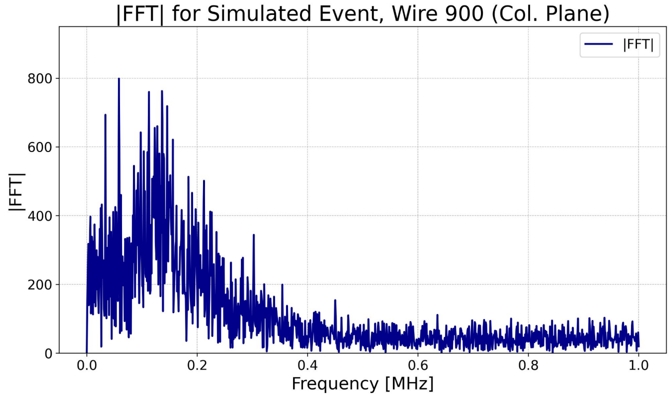
ICEBERG Data





ICEBERG Simulation





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Simulate Noise – Coherent – Proposal

C_k lagged correlation matrices by frequency band

$$S_f = \sum_{k=-3}^{3} C_k^{\text{freq band}} e^{-2\pi i f k/T}$$

Scale by |FFT|

Sample From $\mathcal{CN}(0, S_f)$

Calculate IRFFT

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Concluding Thoughts

Incoherent noise model and sim is all in a Github:

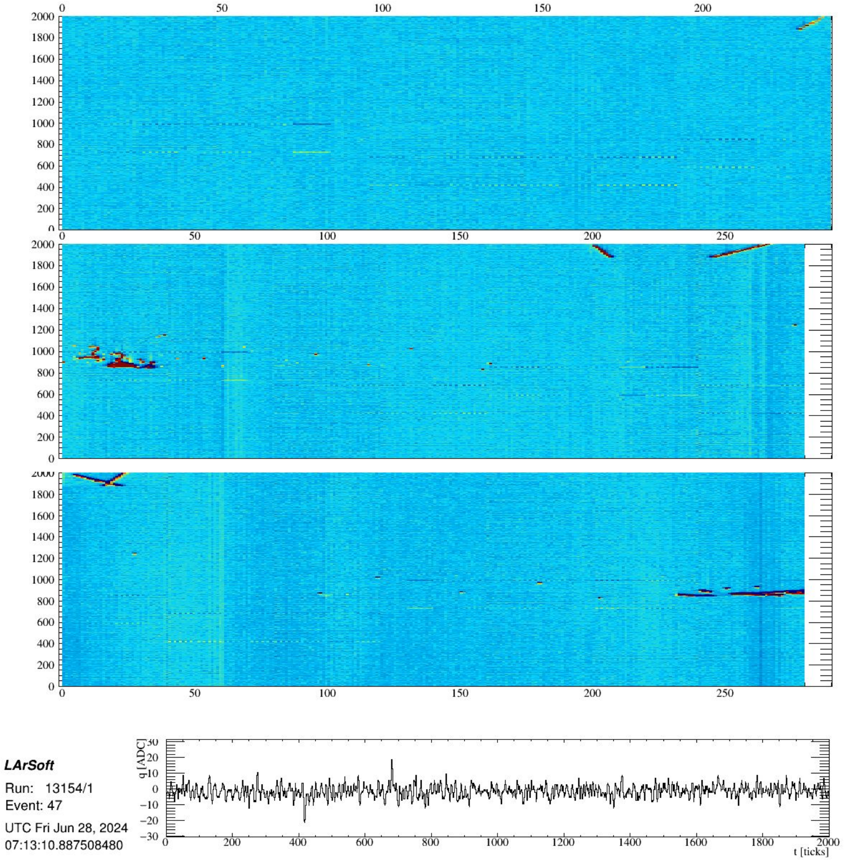
https://github.com/mking99456/Update_Noise_Model/tree/master

To do: test and validate correlated noise sim algorithm

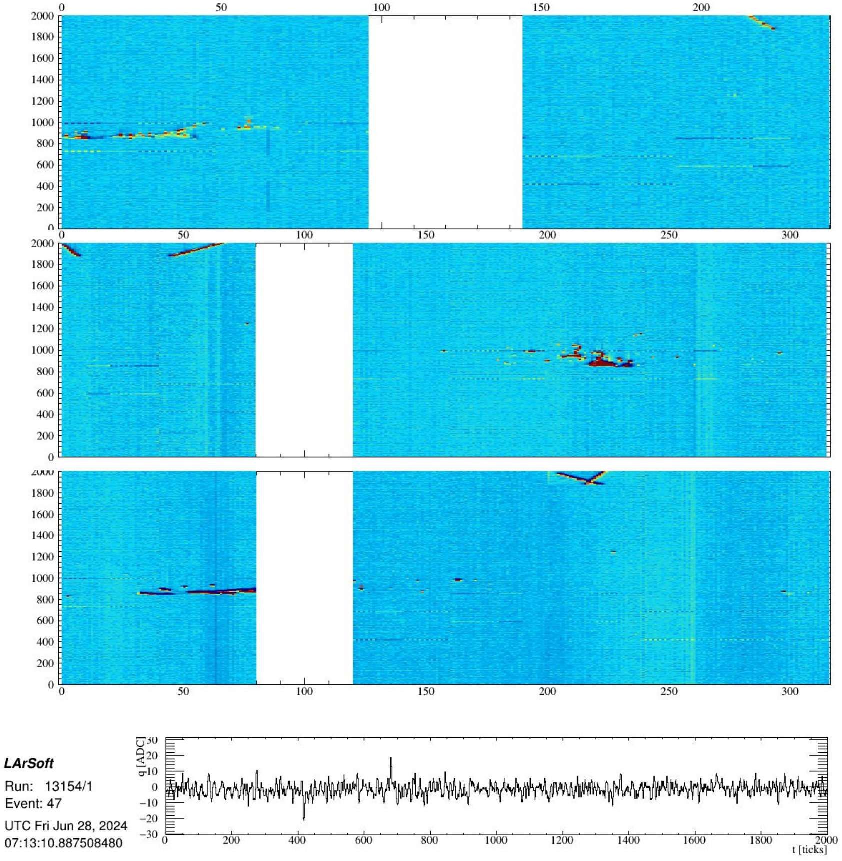
- Happy to discuss ideas for implementing correlated noise sim
- Happy for other improvements and validations!

Backup Slides

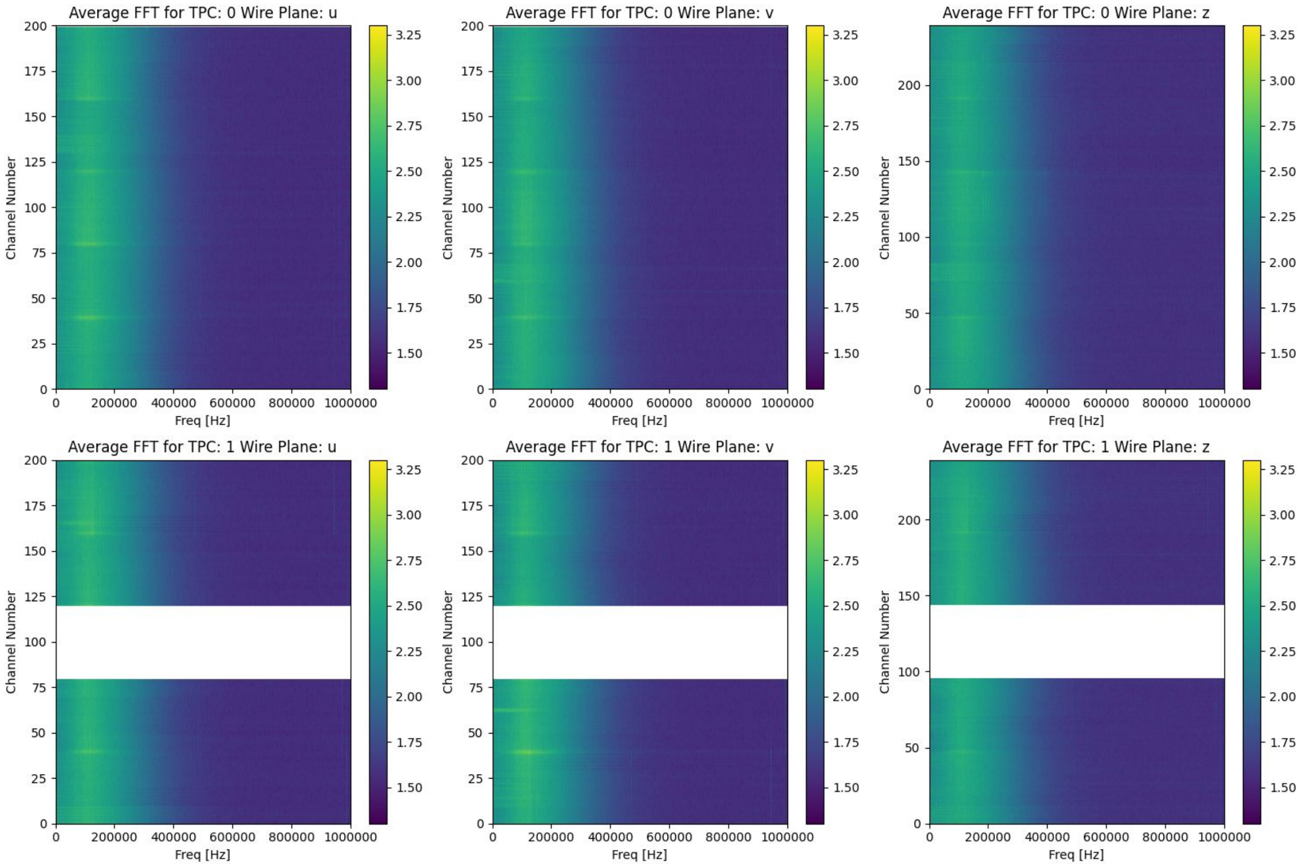
Pre-processing / Selecting Noise Events



No.



Model Noise Conditions in ICEBERG



Model Noise -- Post-processing

ADC -> mV

- Wirecell wants the noise model in **mV**, not **ADC**.
- ICEBERG has **14-bit ADCs** and has a dynamic range of about **1.4 V**. So, I multiply everything by a conversion factor of:
- ADC_to_mV = 1.4 V/2**14 ADC = 0.0854 mV/ADC

Numpy -> Json

- /exp/dune/data/users/mking/ICEBERG_Noise_Ar_39/iceberg_noise/Update_Noise_Model_09292024/convert_iceberg_noise_model.py
- Creates two files for use in WireCell:
  - iceberg_group_to_channel_map_incoh.json.bz2
  - iceberg_noise_model_incoh.json.bz2

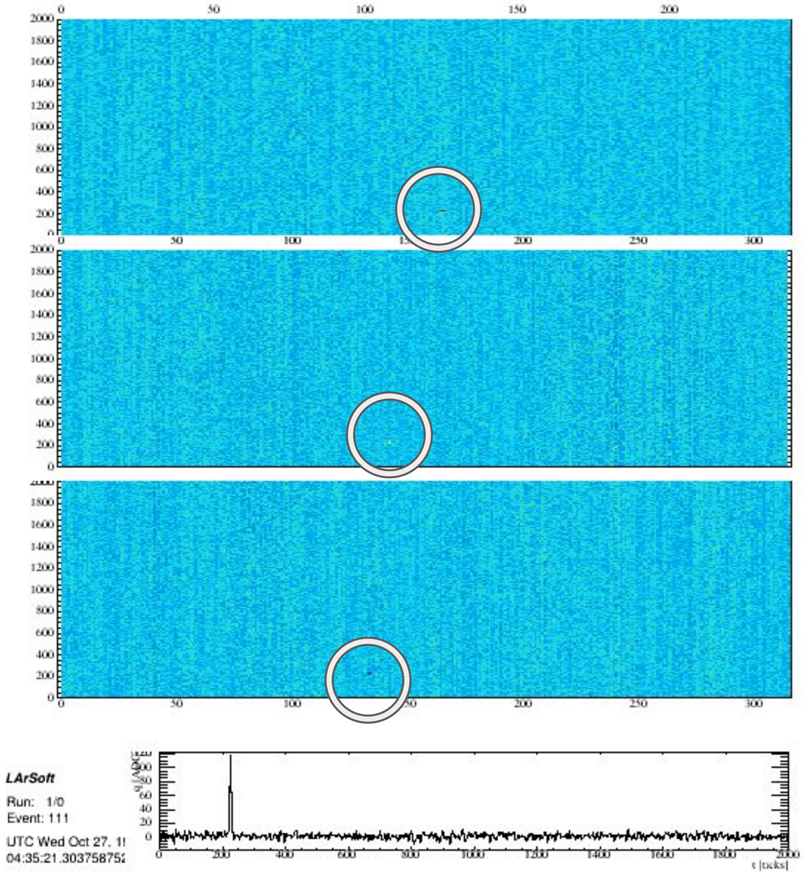
Inside the Guts of the Simulation

The simulation uses:

`/exp/dune/data/users/mking/ICEBERG_Noise_Ar_39/sim_v09_90_00d00/icegen_ar39.fcl`

- dunesw v9_90_00d00
- A custom noise model (made in the above fashion) in WireCell
- WireCell handles all of the noise simulation and detector drift / signal processing.
- Drift parameters from wirecell_dune.fcl in tpcrawdecoder process – not custom but worth keeping an eye on
    - DL: 4.0 // Longitudinal diffusion constant [cm2/s]
    - DT: 8.8 // Transverse diffusion constant [cm2/s]
    - lifetime: 35.0 // Electron lifetime [ms]
    - driftSpeed: 1.565 // Electron drift speed from SP measurement
- Custom parameters in experiment/iceberg/params.jsonnet:
    - resolution: 14 //14-bit ADCs – default
    - shaping time: 2 //microseconds – default, same as run 13154
    - **gain 7.8 mV/fC** //from run 13154 (new default from 14 mV/fC)

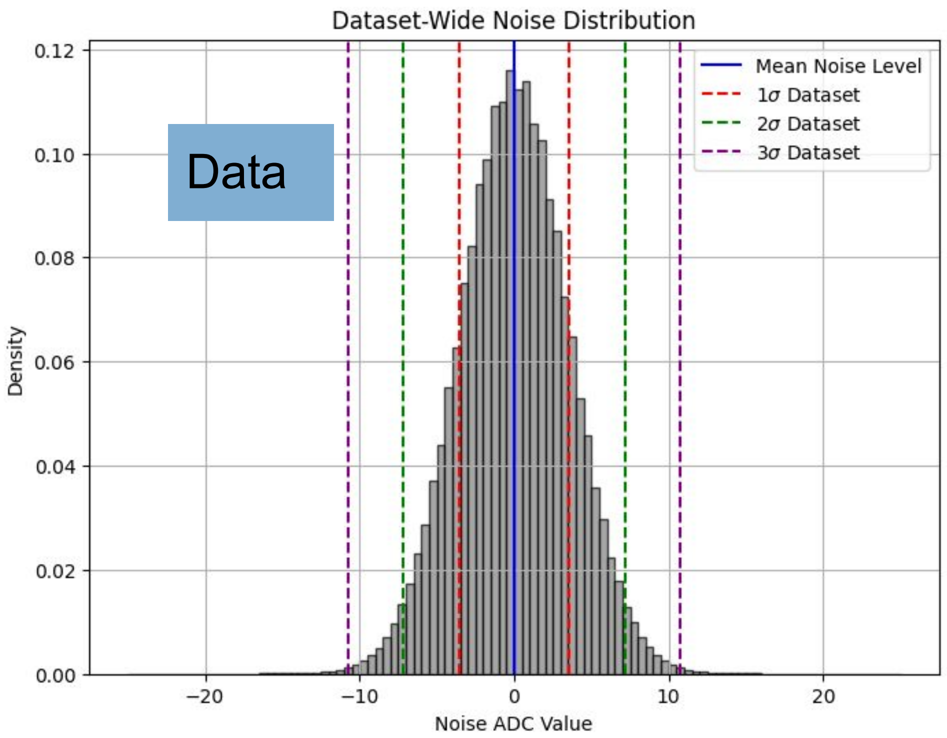
Simulated Event Display

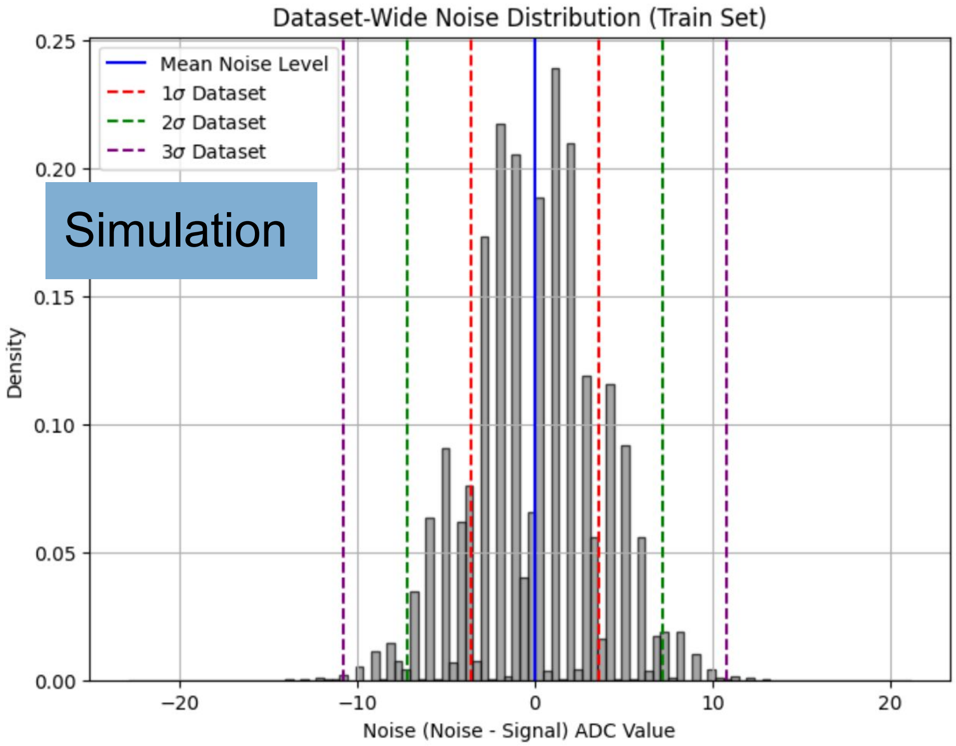


White Circles are Ar39 – I simulated both simultaneously.

Noise simulation is incoherent: no wire-to-wire correlations in time

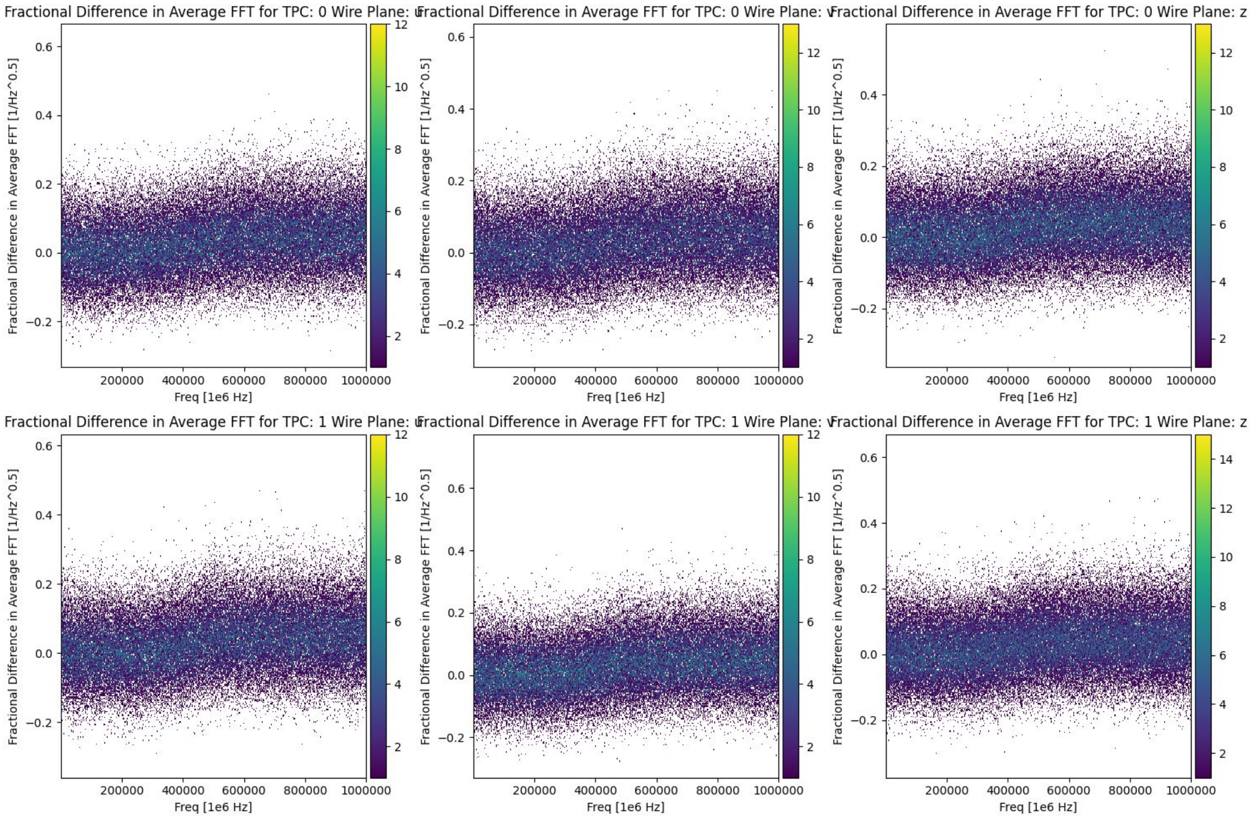
Validate Simulation





Validate Simulation

Fractional Difference in Avg FFT:
(Sim - Data) / Data



Validate Simulation

Fractional Difference in Avg FFT:
(Sim - Data) / Data