Noise-Filtering & Saturation/ Non-Linearity in SBND

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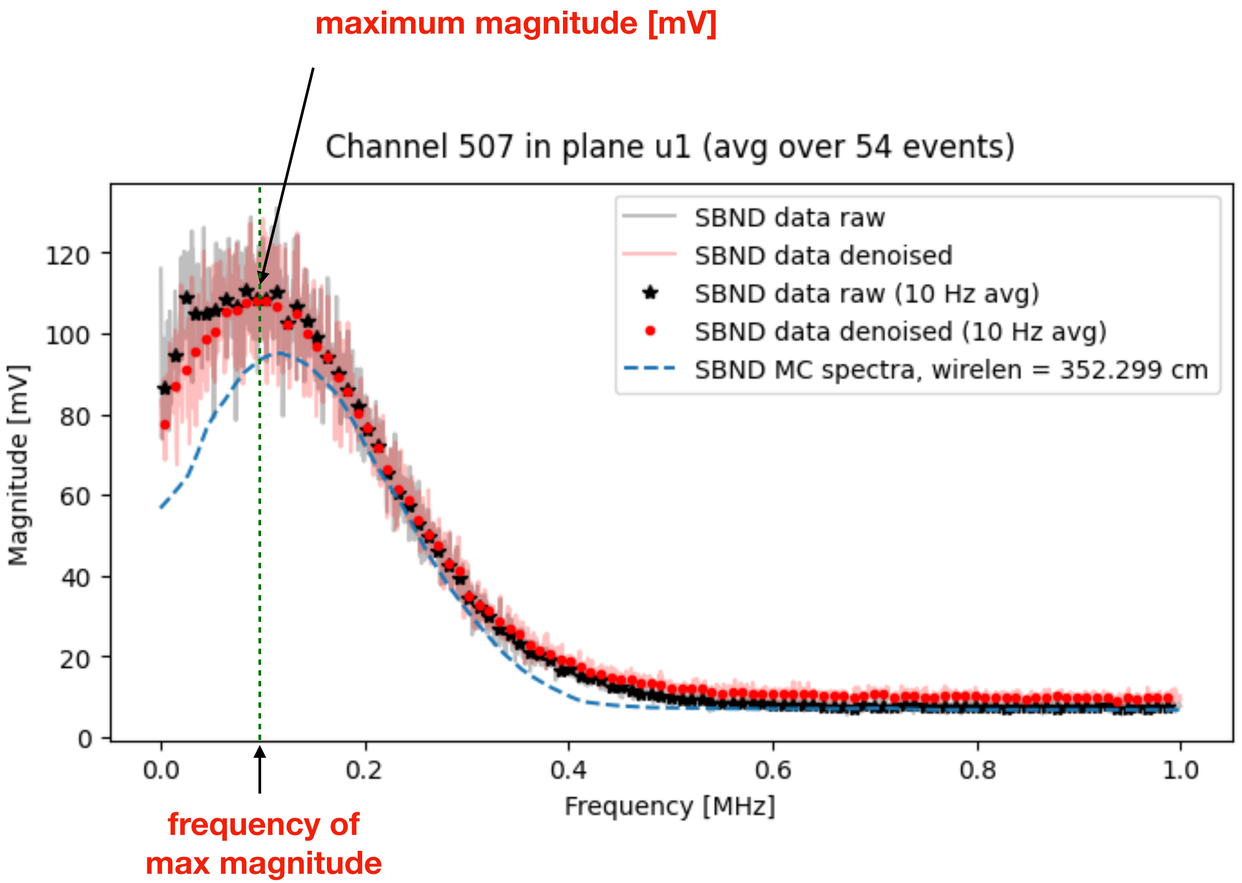
WireCell Meeting
October 17th, 2024

Outline

- noise-filtering performance in SBND
  - evaluation of noise-removal in data
  - signal protection in simulation

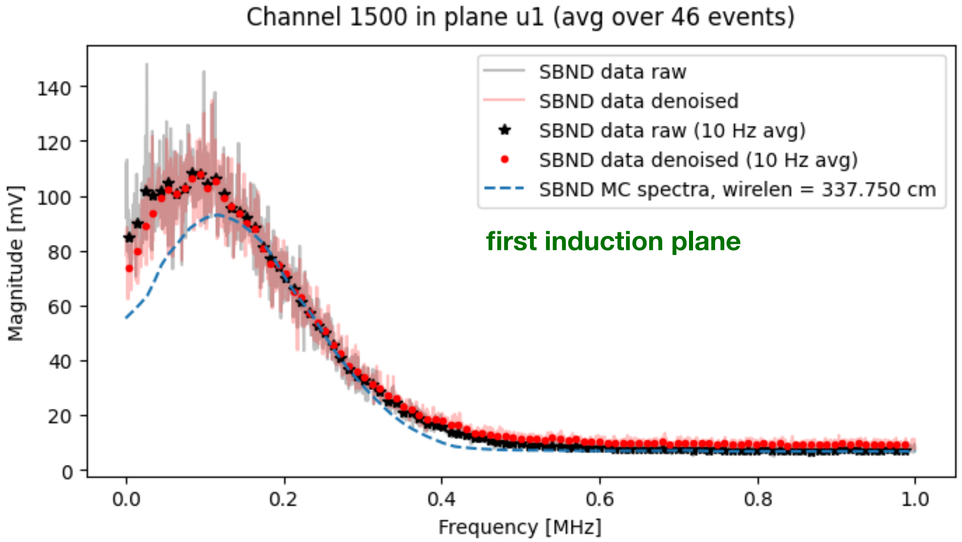
- non-linearity model and saturation/FE baseline fit

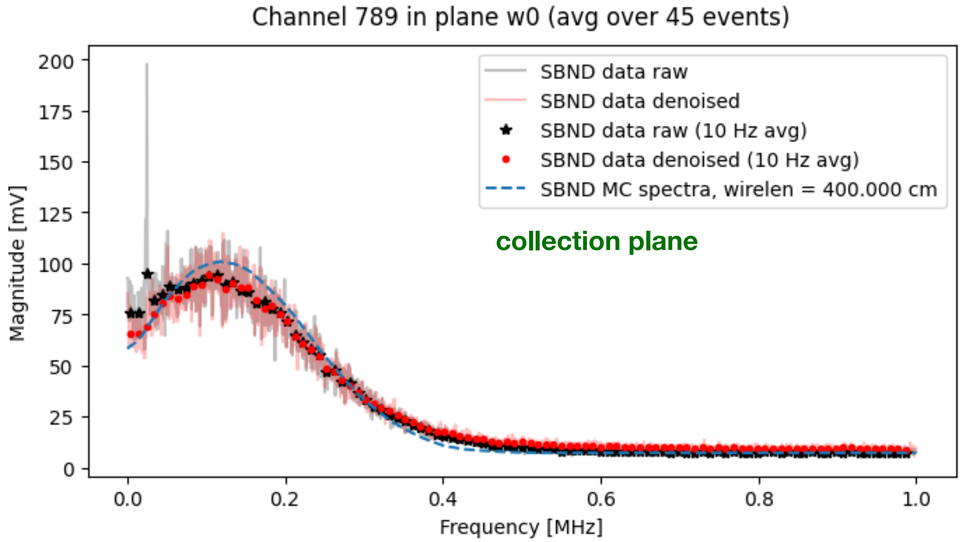
Noise Spectra Evaluation

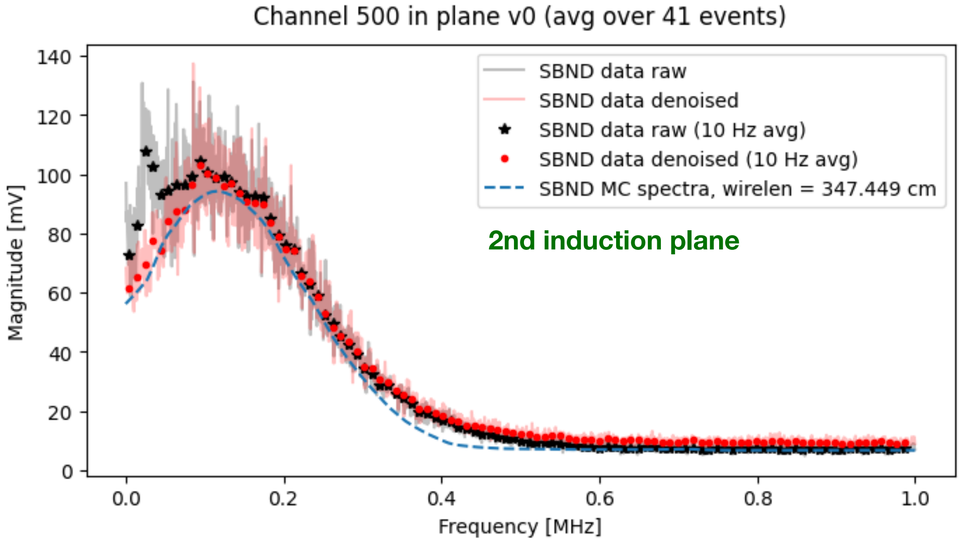


- comparing noise spectra from data, on a channel-by-channel basis, between:
  - raw waveforms (no filtering)
  - de-noised waveforms
  - SBND MC spectra
- can compare the overall power for each channel with extrapolated PD SP noise spectra
  - PD SP has same CE

Noise Spectra Evaluation

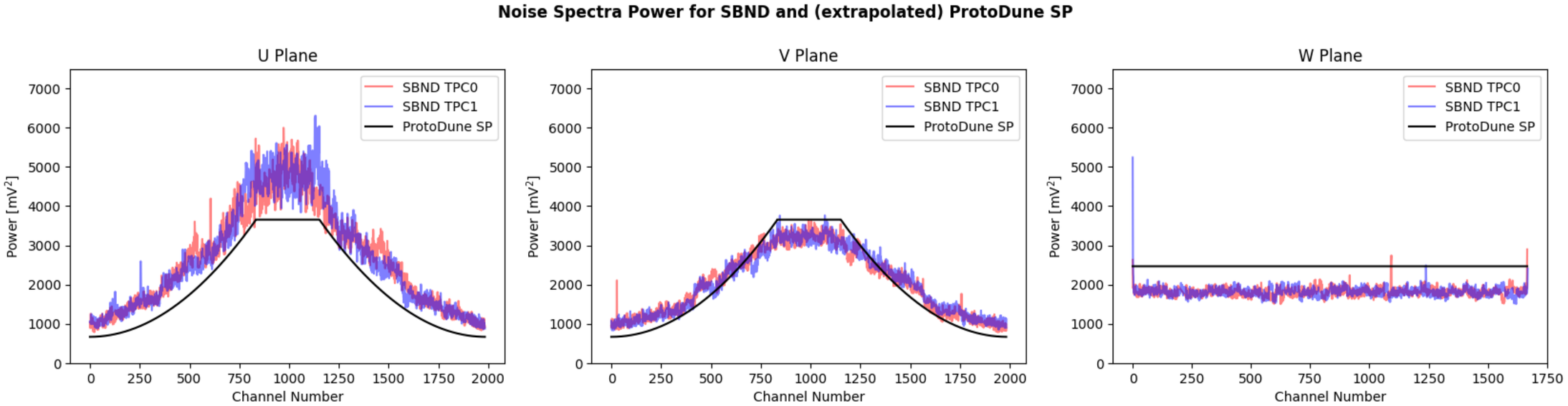






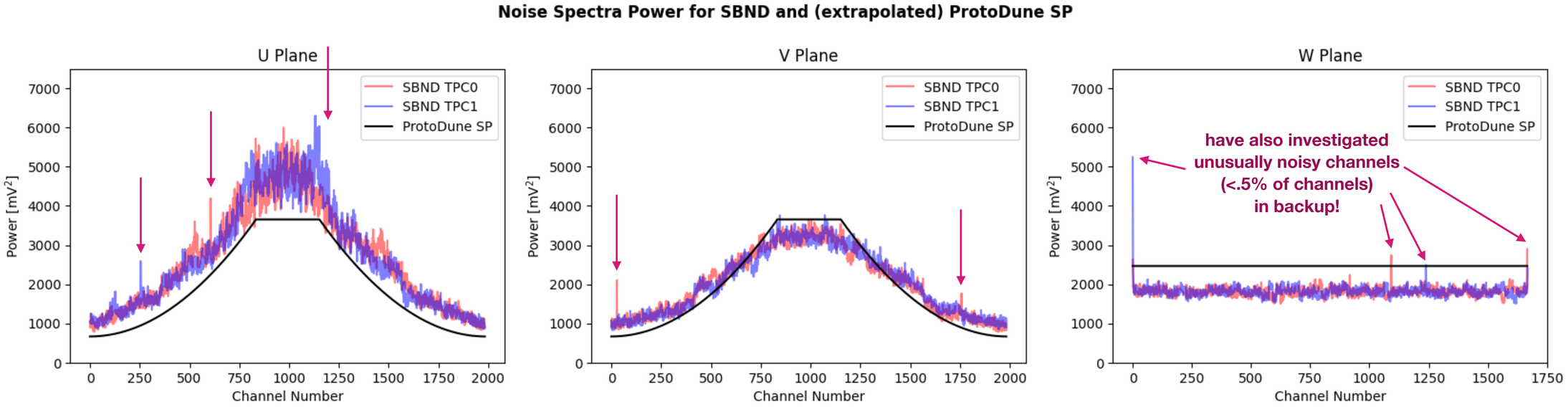
- in general, using only *single* + *grouped* noise filters works very well in SBND!
- coherent noise peaks (mainly at low frequencies) are removed without specialized treatment

SBND vs. PD Noise



- overall, the power of the noise spectra in SBND is comparable to extrapolated ProtoDUNE SP noise spectra
  - U plane is slightly more noisy in SBND; we do not have a shielding plane
  - V and collection planes are similar in power between SBND/PD SP

SBND vs. PD Noise



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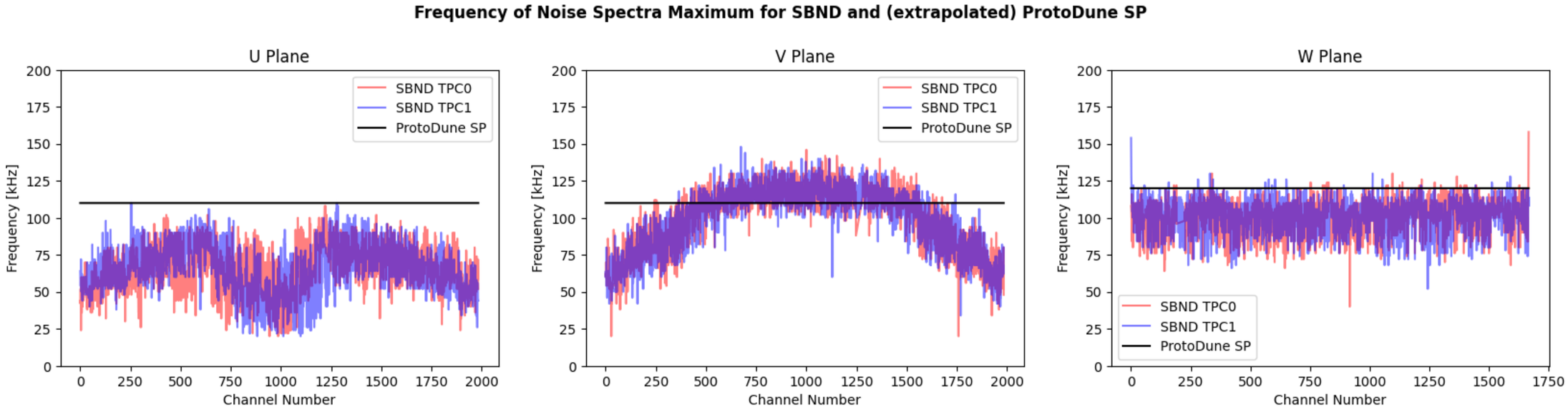
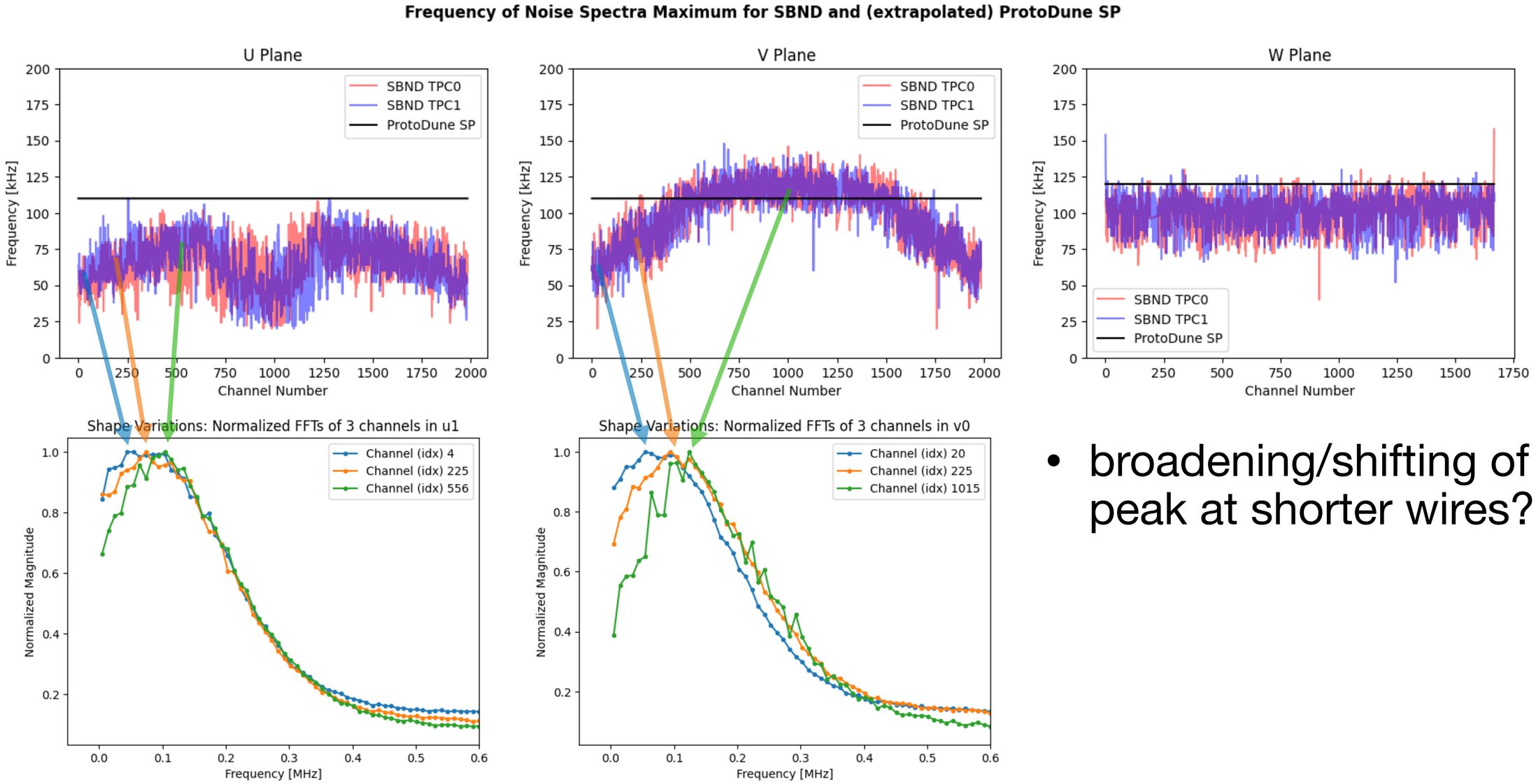
SBND vs. PD Frequency of Maximum



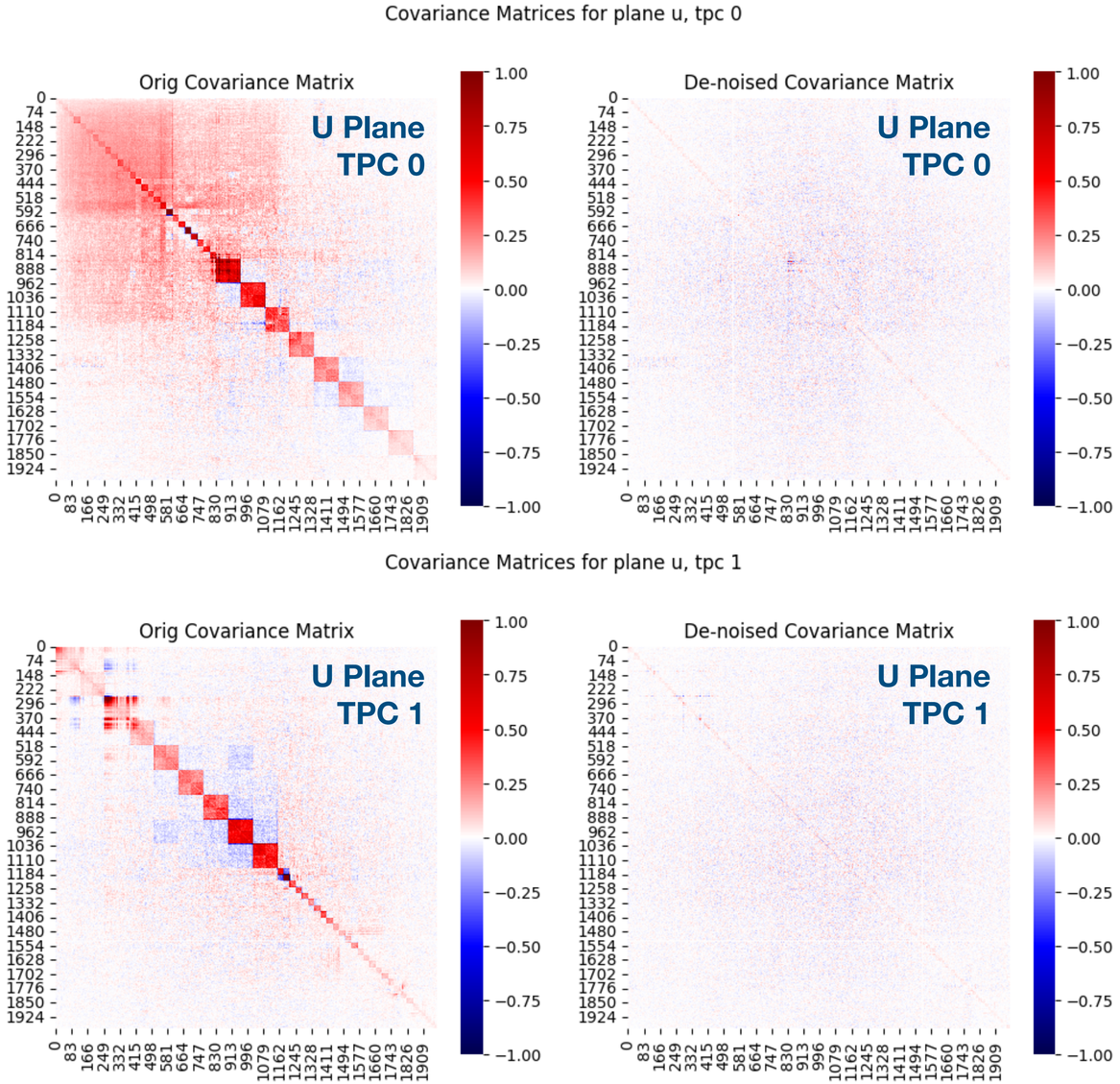
- the shape/peak of the noise spectra in SBND seems to be somewhat channel-dependent, potentially wire-length dependent

Shape Variations of Noise Spectra in SBND



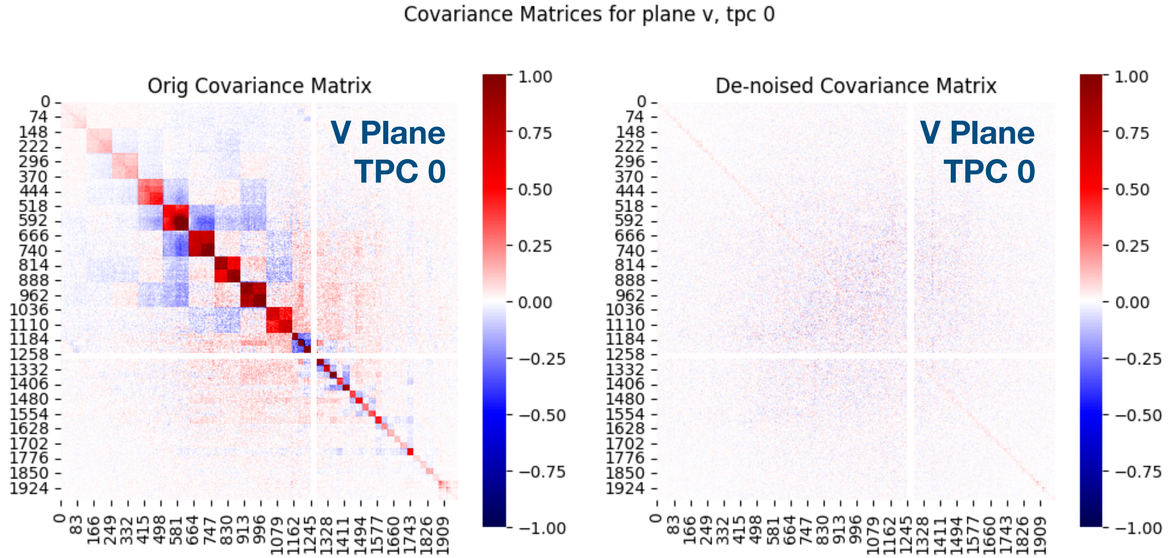
- broadening/shifting of the peak at shorter wires?

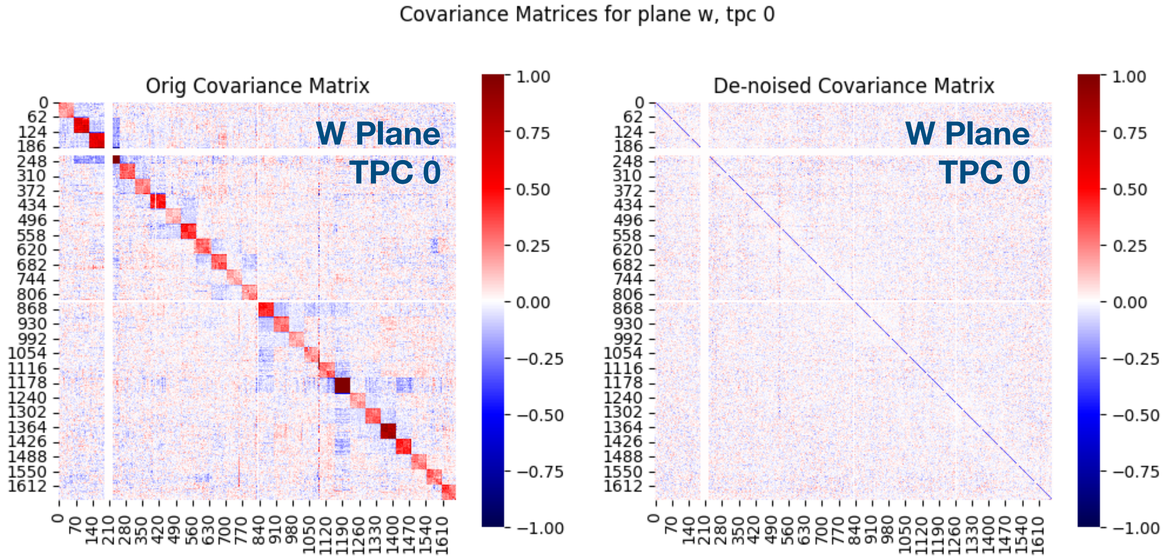
Covariance matrices

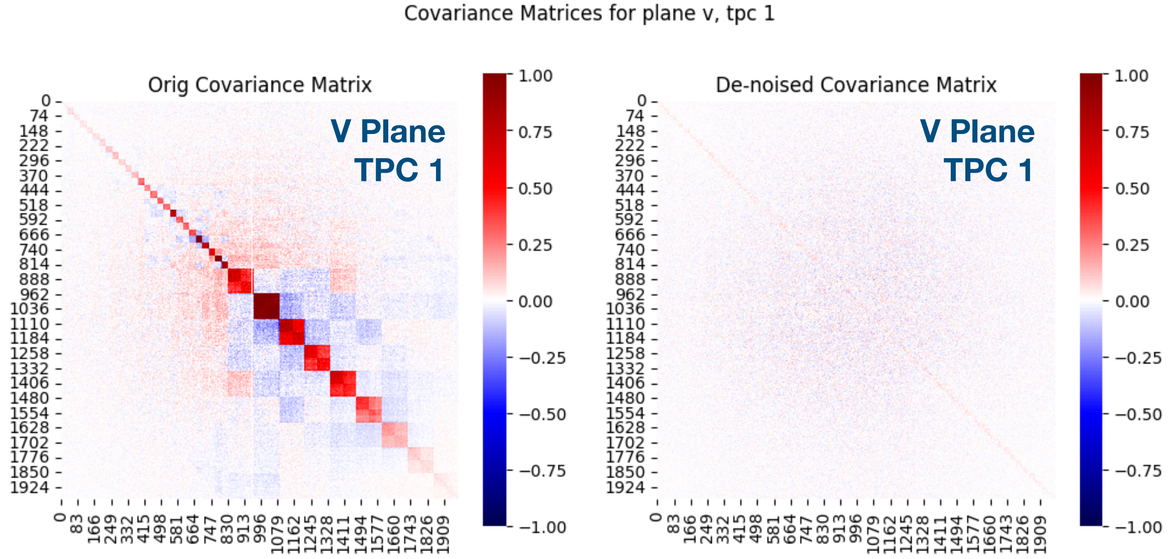


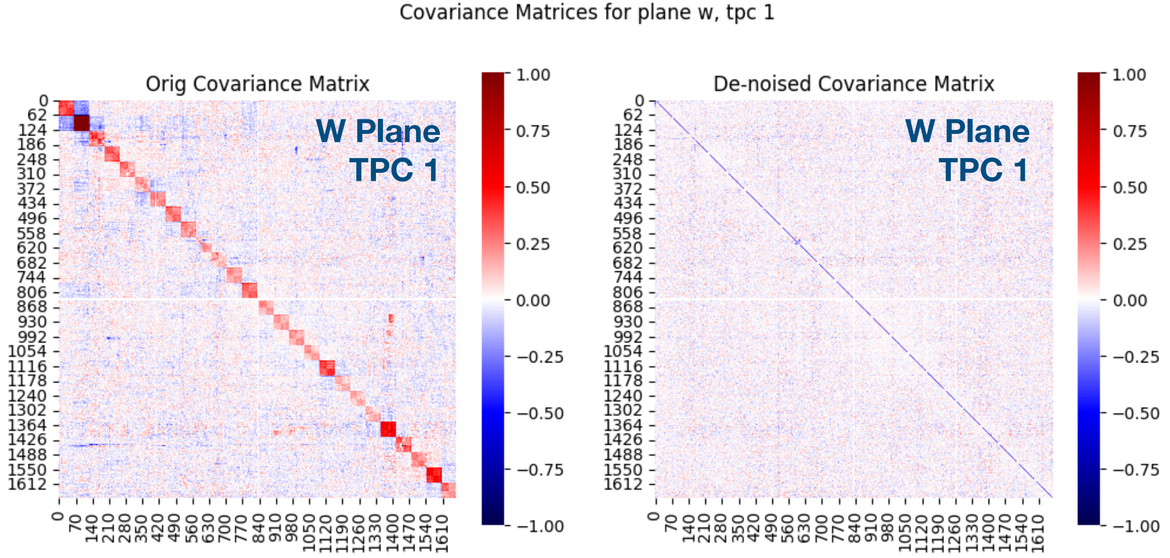
- can also evaluate coherent noise removal performance by checking covariance (or correlation) matrices
  - correlation matrices in backup!
- using covariance matrix with narrow colorbar limits allows us to view the structure of coherence more clearly
- for SBND in general, coherent noise is very manageable and the removal is straightforward

Covariance matrices







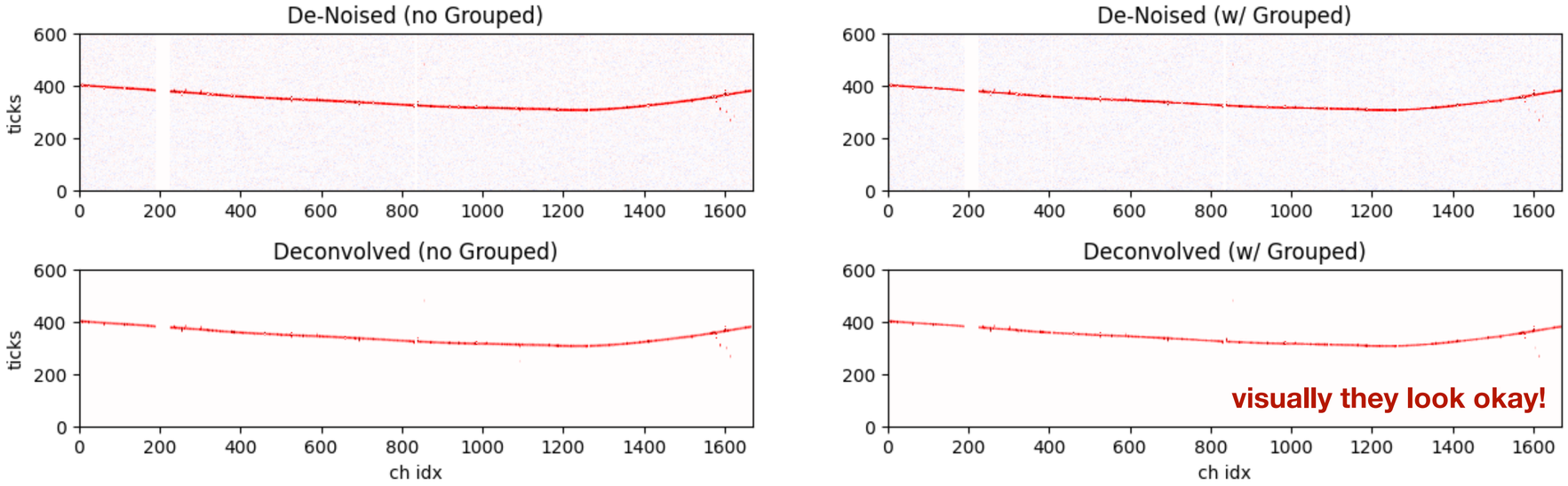


MC Signal Protection

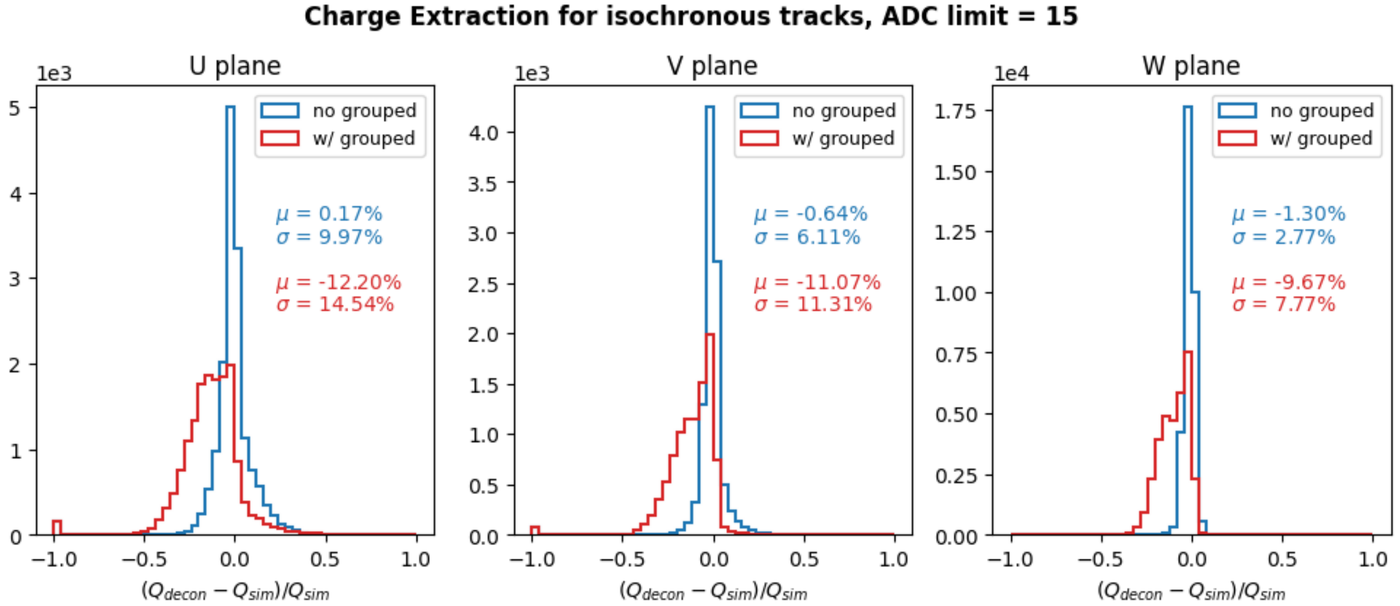
- given that the current parameters of noise-filtering work well for coherent noise removal, we also need to check using MC that signal is protected

  1. simulate isochronous muon tracks for each wire plane

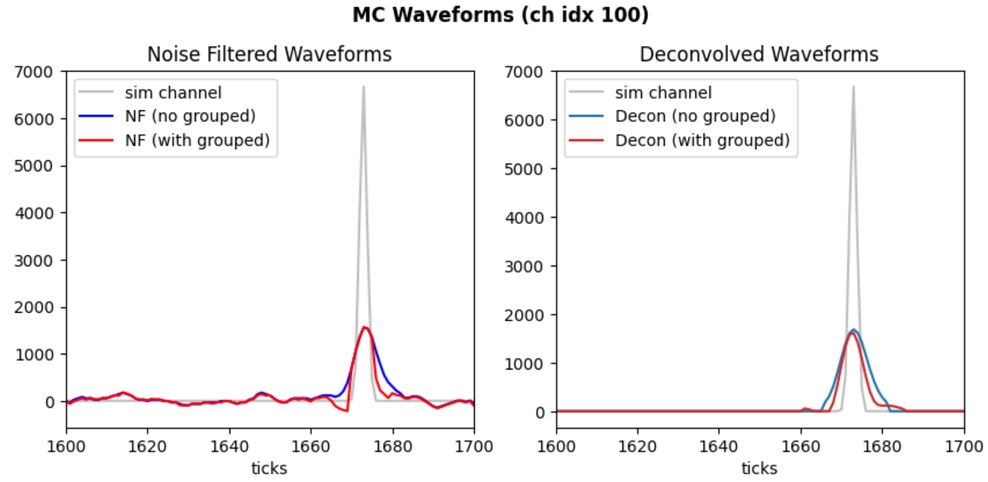
  2. evaluate charge bias and resolution from deconvolved waveforms



MC Signal Protection

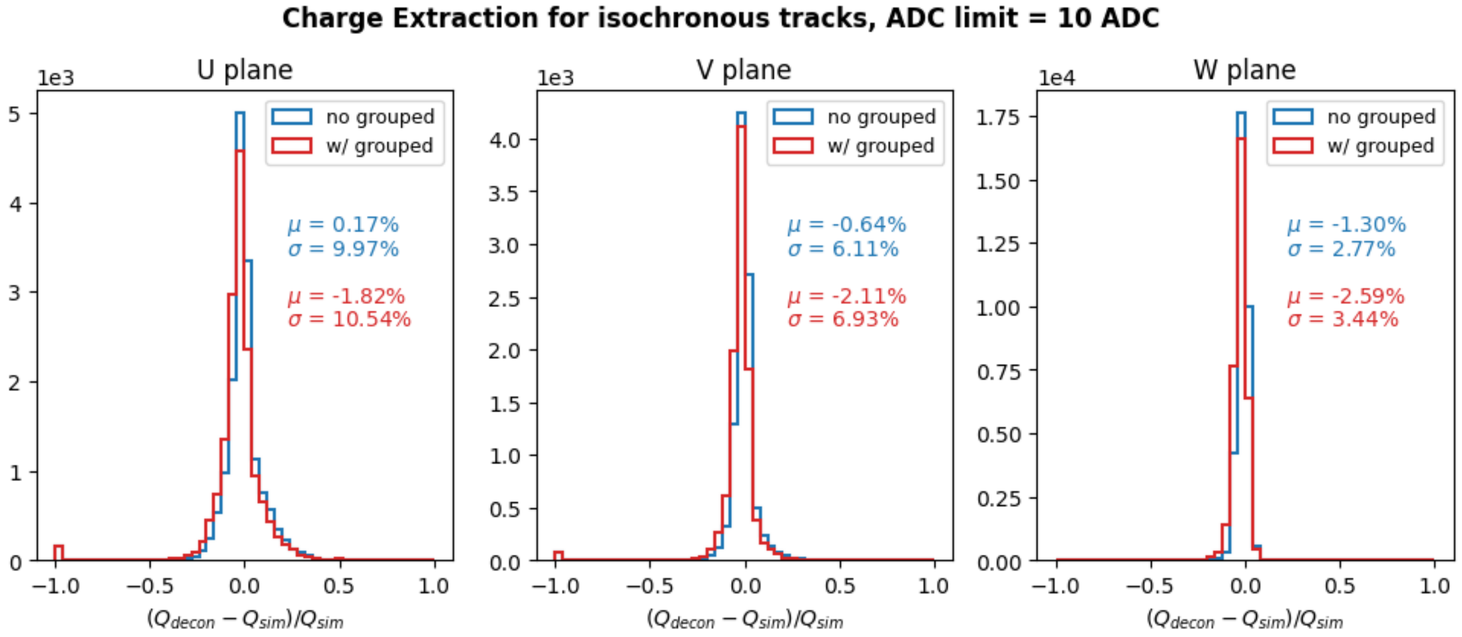


- however, clearly there was significant signal removal using the existing grouped filter parameters
  - edges of signal ROIs are identified as noise



MC Signal Protection

- we tuned *one* parameter for coherent noise filtering
  - changed *adc_limit* from 15 → 10, effectively *lowering* the threshold for signal identification
  - worked perfectly!
- the spectral power + cov matrices are nearly identical, so coherent noise is still being removed successfully with this parameter change



change in bias and resolution on the <2% level

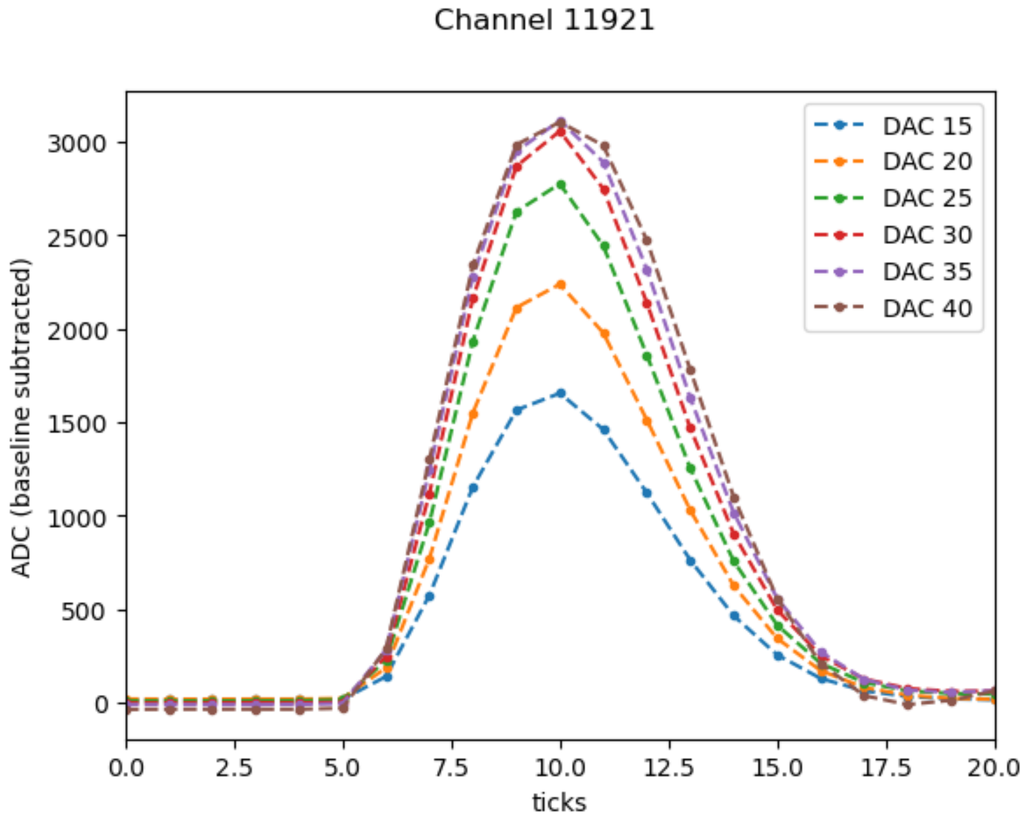
Noise Filtering: Summary

- performed comprehensive evaluation of coherent noise removal in SBND
  - compared power with PD SP, remaining noise in SBND is comparable to expected intrinsic noise
  - no indications of excess noise or pickup noise on >99.5% of channels
- performed validation of signal protection in MC using isochronous tracks
  - tuning was straightforward!
- last task: identify/evaluate remaining teardrop effects in MC/data

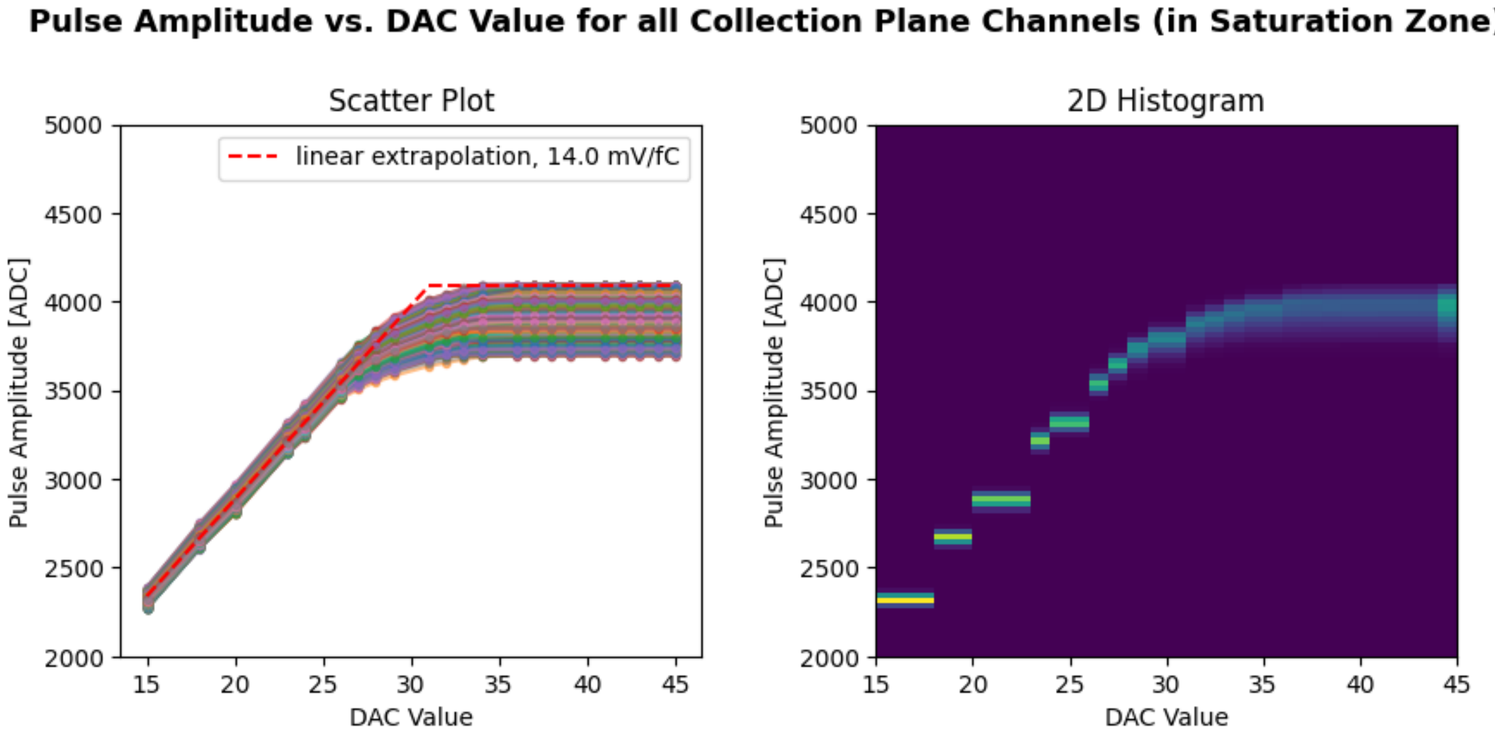
CE non-linearity & FE Baseline variations

Non-Linearity + FE ASIC Baseline Variations

- non-linear region has not been studied and is not simulated
- additionally, due to variations in the FE ASIC baseline, the effective dynamic range can:
  1. be smaller than expected
  2. vary channel by channel
- using SBND pulser data, we can make measurements in the non-linear region
  - focus on collection plane wires (for now)



Non-Linearity + FE ASIC Baseline Variations

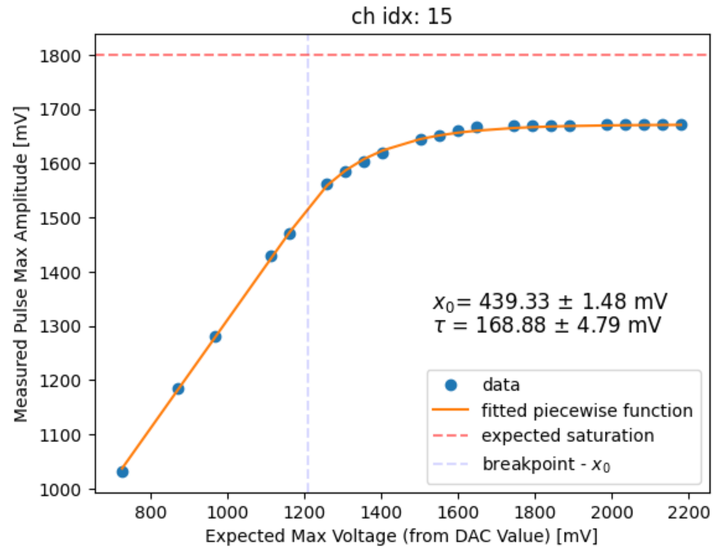


- was able to take finer resolution pulser data to properly parametrize the non-linear region
- variation in FE ASIC baseline results in lower saturation voltage

Non-Linearity model + FE Baseline Fit

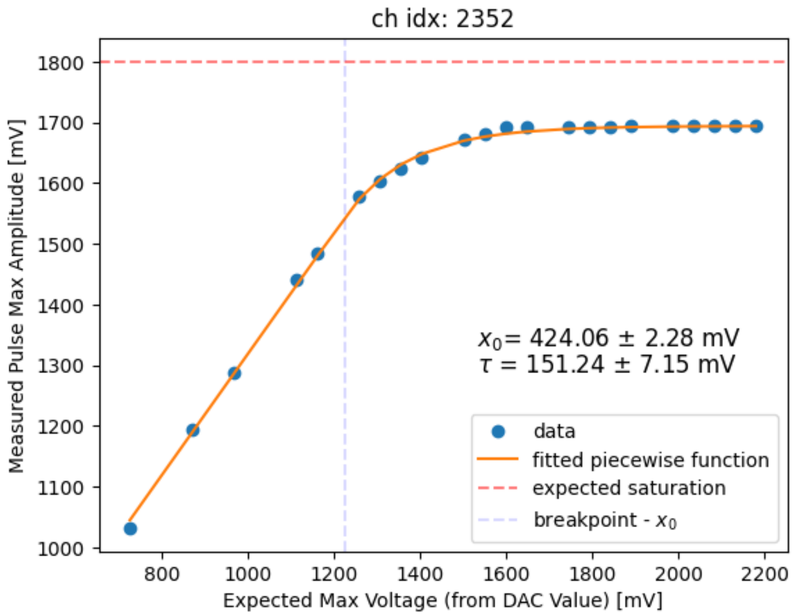
- performed a fit for all collection channels using a piecewise linear+non-linear model

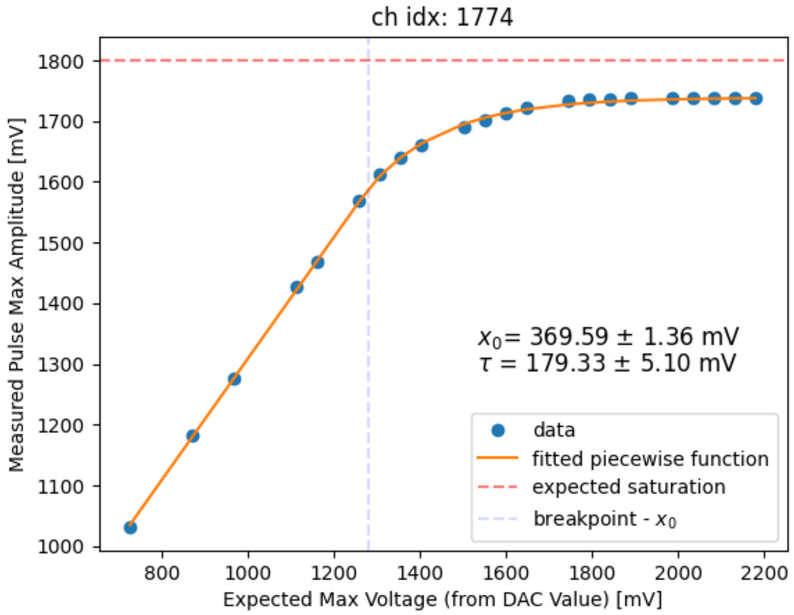
$$y = \begin{cases} x + x_0 & x < x_b - x_0 \\ \left(V_{sat} - x_b\right) \cdot \left(1 - \exp(-\frac{x + x_0 - x_b}{\tau}\right) + x_b & x \geq x_b - x_0 \end{cases}$$

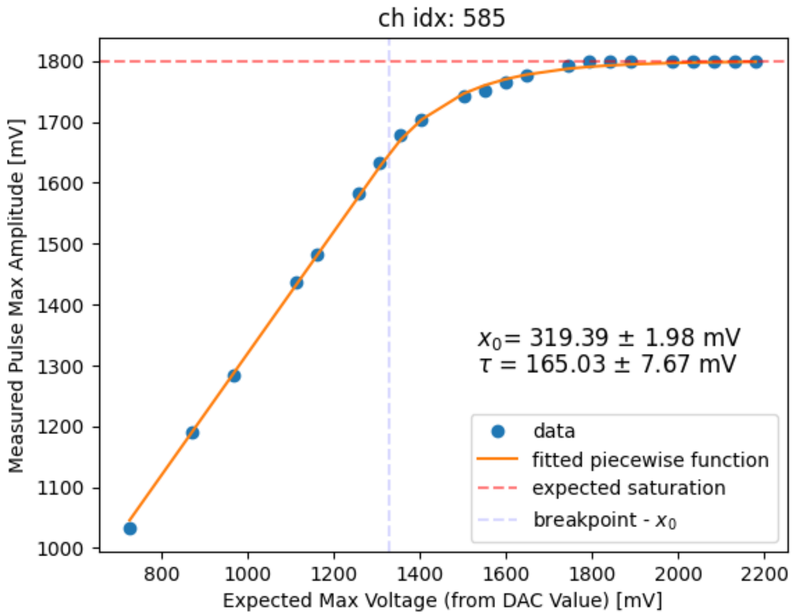


- x_0 is the fitted FE baseline (essentially an x-axis shift)
- x_b is the "break-point" voltage between the linear → non-linear model
  - determined to be **1650 mV** for **all channels!** (we set it now to be constant)
- τ is the exponential constant (describes shape of non-linear region)
- V_{sat} is the observed saturation value, correlated with x_0 and also folds in the ADC baseline
  - measured directly from data, not a free parameter in the fit

Non-Linear/Saturation Fit performance

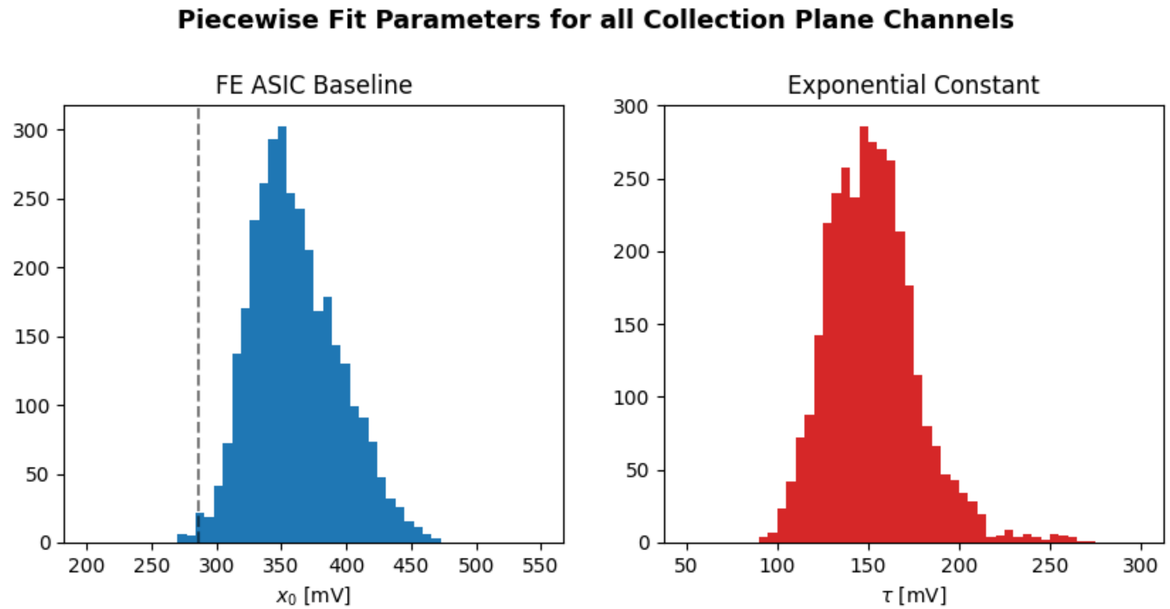




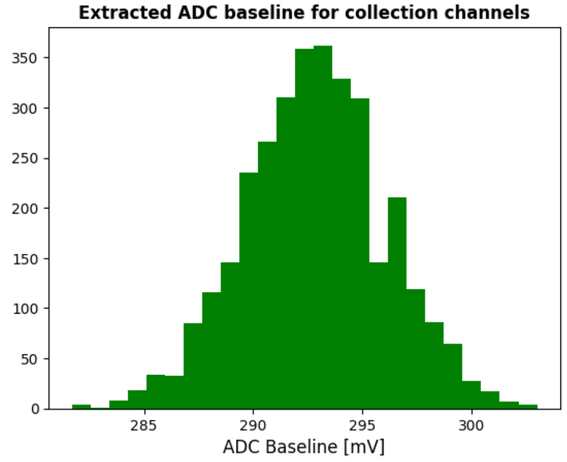


- this model works well for channels with smaller and larger FE ASIC baseline values

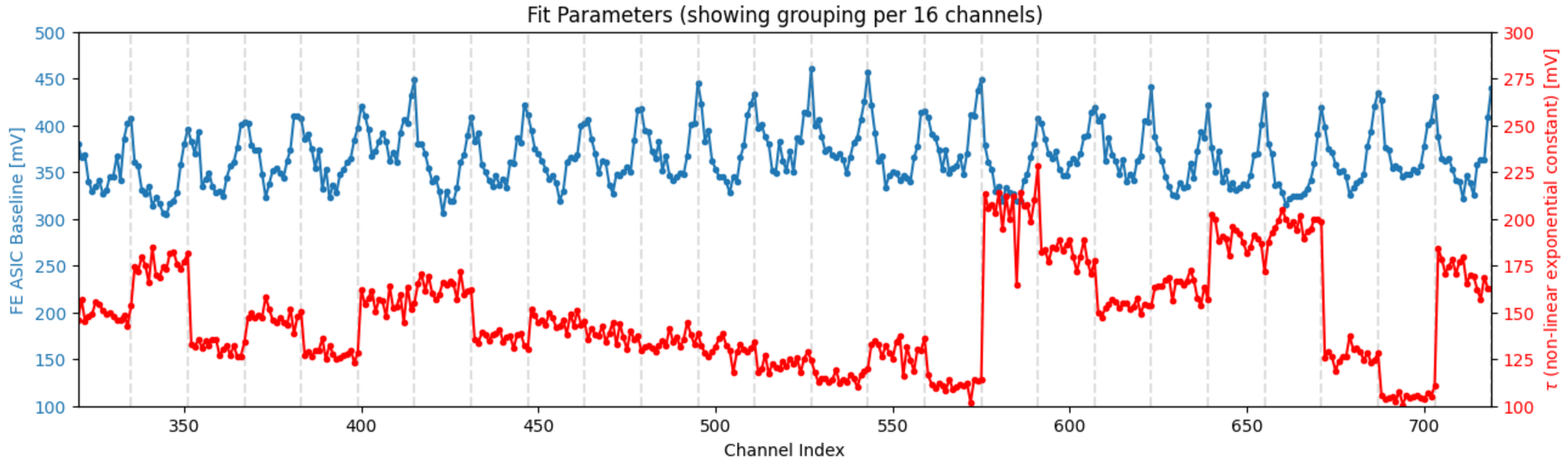
Non-Linear/Saturation Fit performance



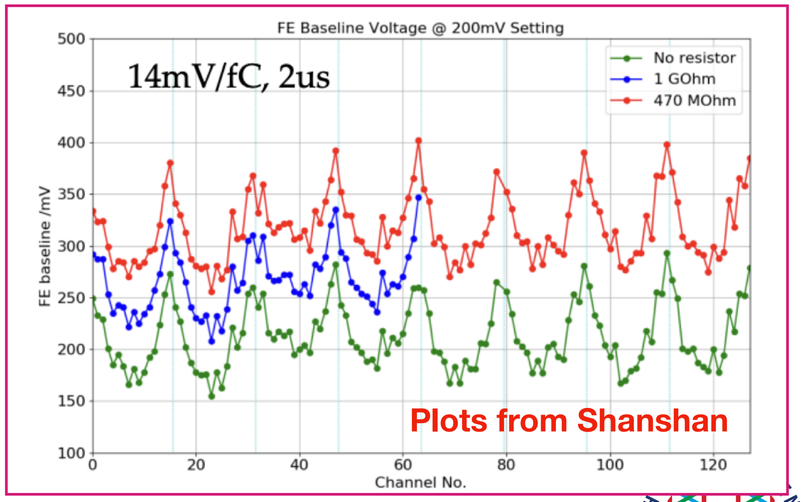
- fit error is <5% for τ, and <1% for x_0
- note: ADC baseline and FE ASIC baseline are different! currently simulated baseline is 286 mV
  - ADC baseline is very stable (only ~15 mV variation across channels), whereas FE ASIC baseline varies ~150 mV



Non-Linear/Saturation Fit performance



- baseline has expected shape/grouping across a single FEMB (16 channels), matches plots from Shanshan
  - good sanity check!
- τ also has grouping across 16 channels



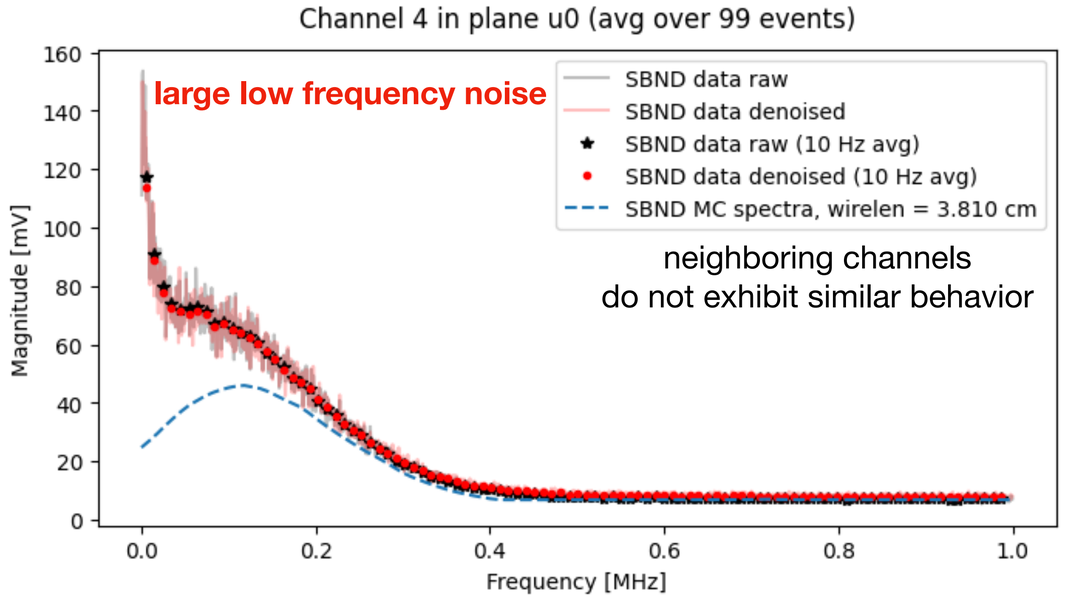
Implementation in WCT

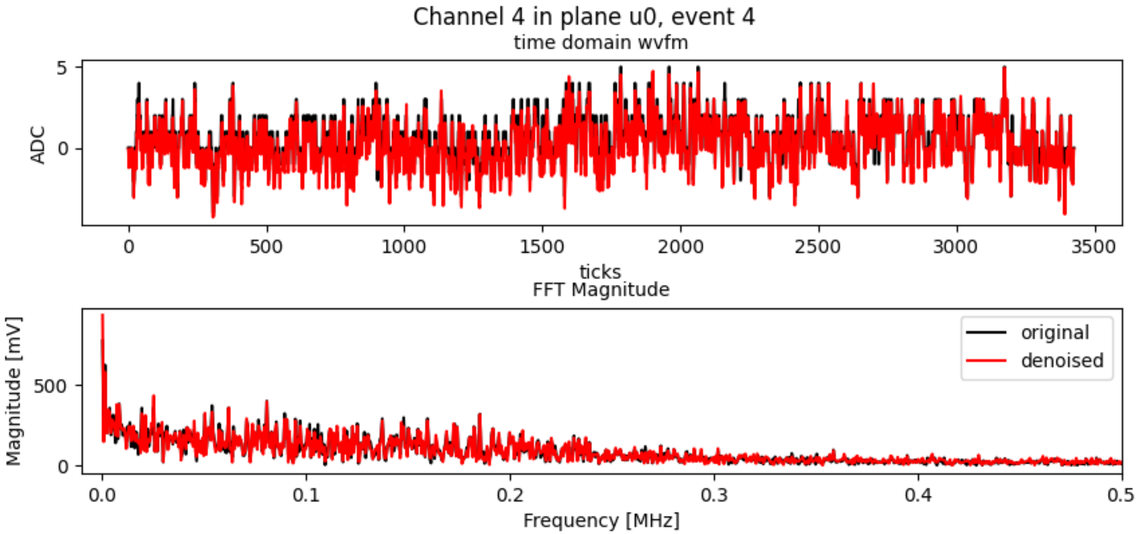
- new Digitizer module in WCT, called *DigitizerNonLinear*
  - given that the model + additions are relatively straightforward, may want to merge into the main Digitizer module after testing + validation
- given the current fit, need *three* parameters per collection plane channel; likely easiest to store in a new json file?
  - parameters are: V_{sat}, x_0, and τ

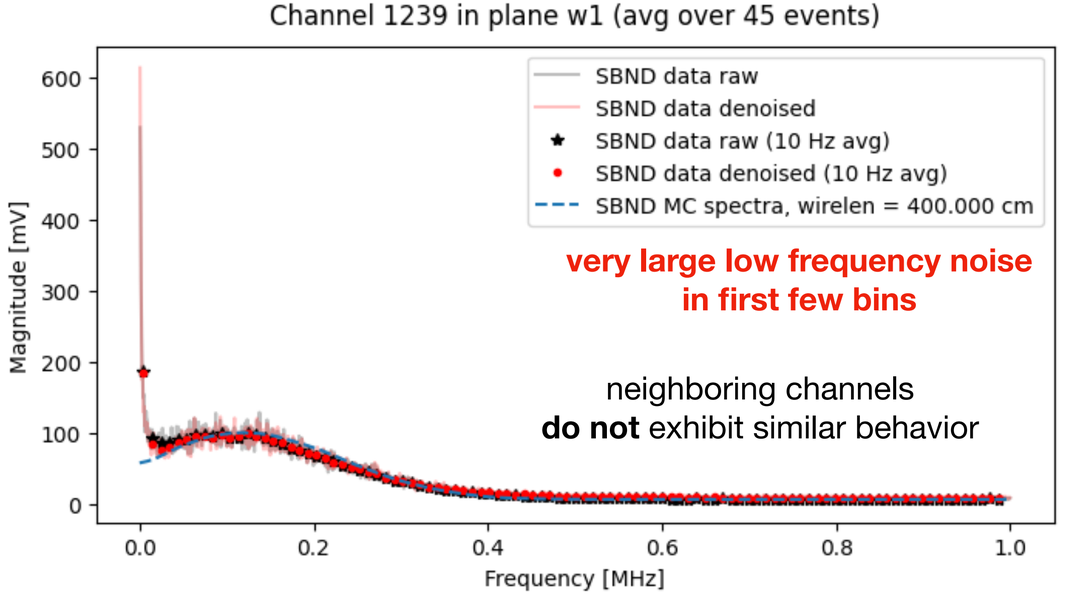
Saturation & Non-Linearity: Summary

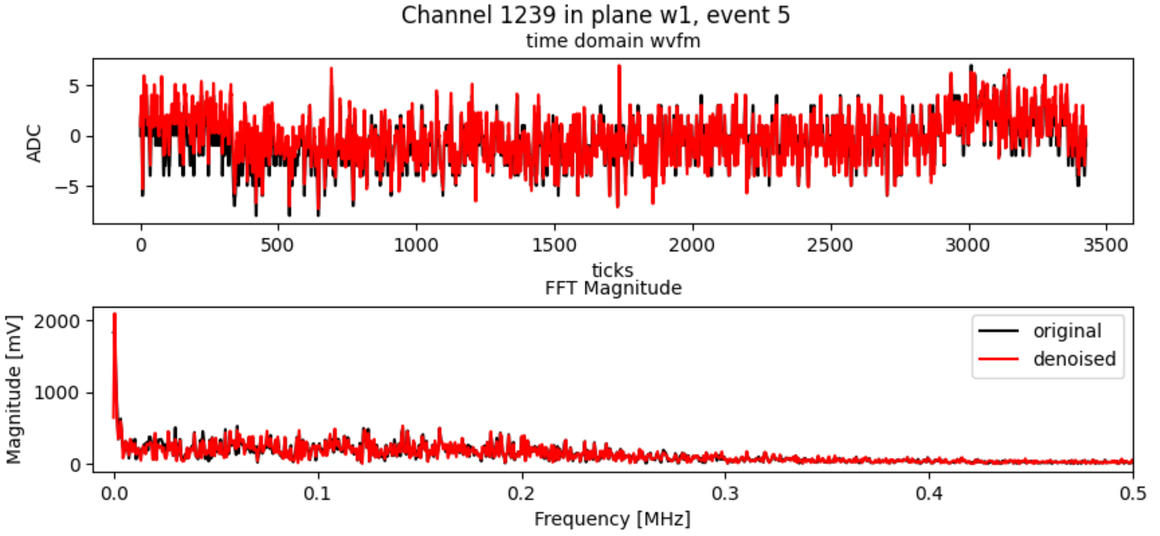
- designed a new model to describe non-linear response of the CE
- able to extract “true” baselines for collection plane channels in SBND, where we expected larger variations and an impact on our true dynamic range
- currently working on implementing the model in simulation in WCT

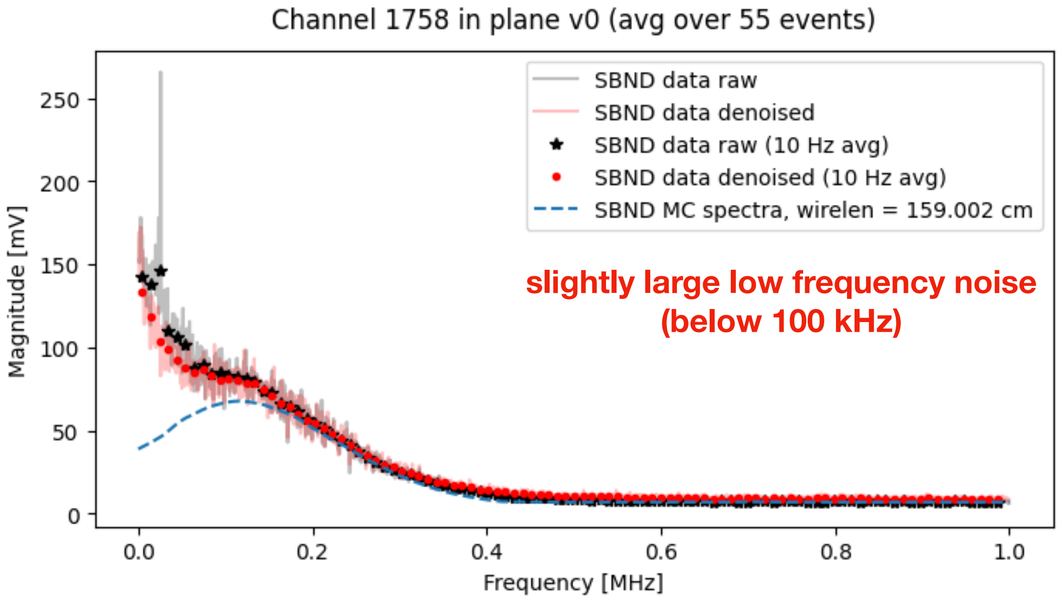
backup

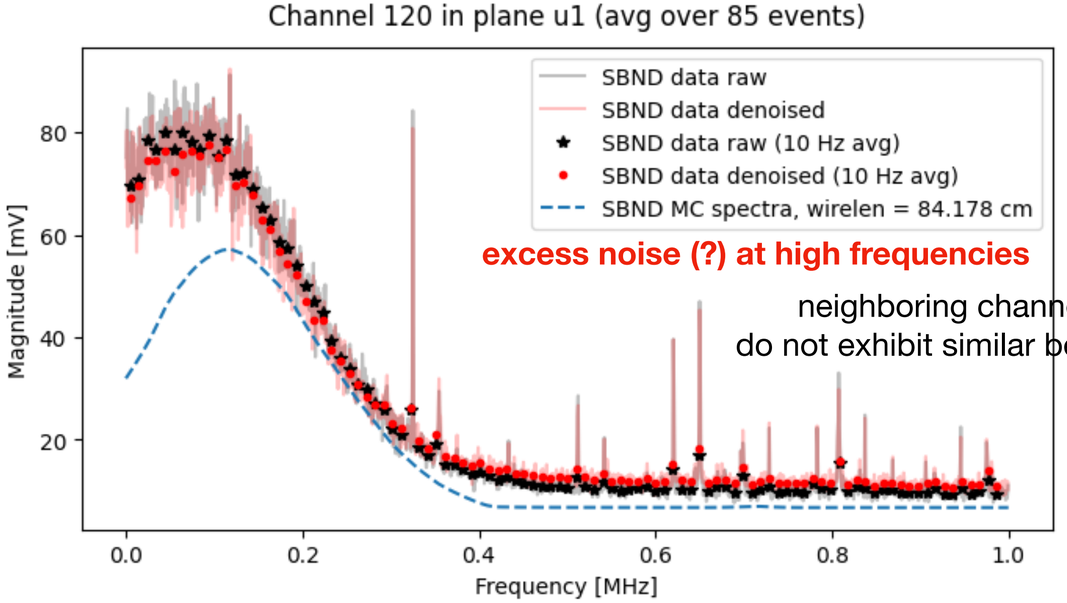

Channel 4 in plane u0 (avg over 99 events)
large low frequency noise
SBND data raw
SBND data denoised
SBND data raw (10 Hz avg)
SBND data denoised (10 Hz avg)
SBND MC spectra, wirelen = 3.810 cm
neighboring channels
do not exhibit similar behavior
Magnitude [mV]
Frequency [MHz]

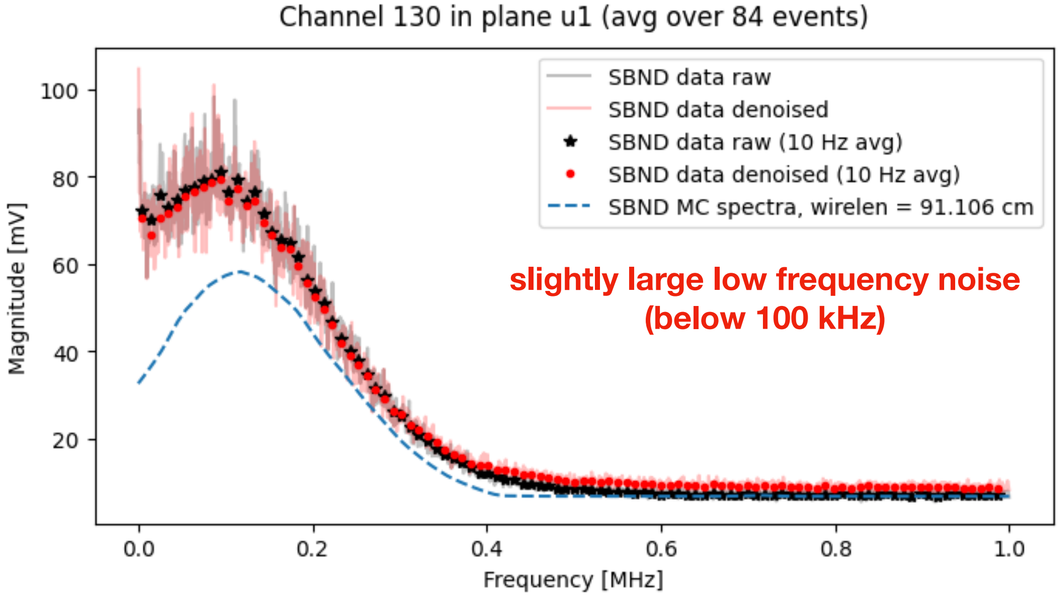

Channel 4 in plane u0, event 4
time domain wvfm
ADC
ticks
FFT Magnitude
original
denoised
Magnitude [mV]
Frequency [MHz]

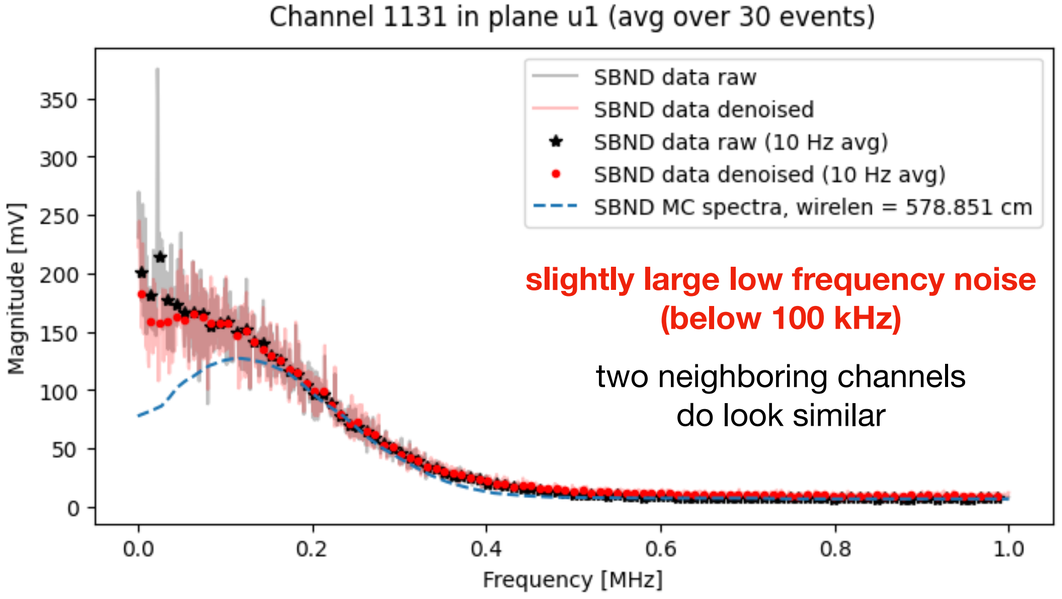

Channel 1239 in plane w1 (avg over 45 events)
SBND data raw
SBND data denoised
SBND data raw (10 Hz avg)
SBND data denoised (10 Hz avg)
SBND MC spectra, wirelen = 400.000 cm
very large low frequency noise
in first few bins
neighboring channels
do not exhibit similar behavior
Magnitude [mV]
Frequency [MHz]

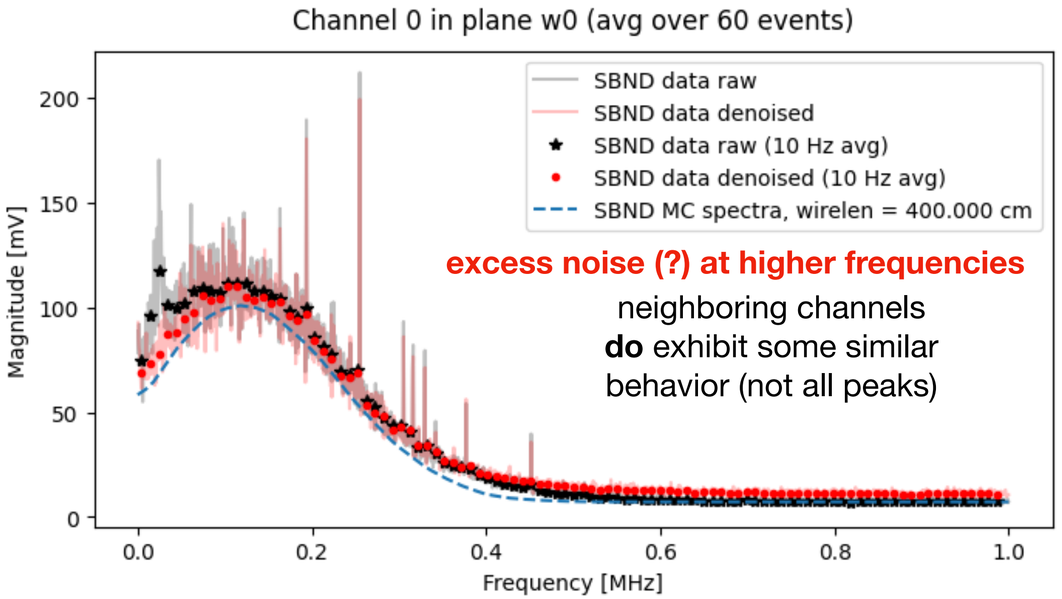

Channel 1239 in plane w1, event 5
time domain wvfm
ADC
ticks
FFT Magnitude
original
denoised
Magnitude [mV]
Frequency [MHz]

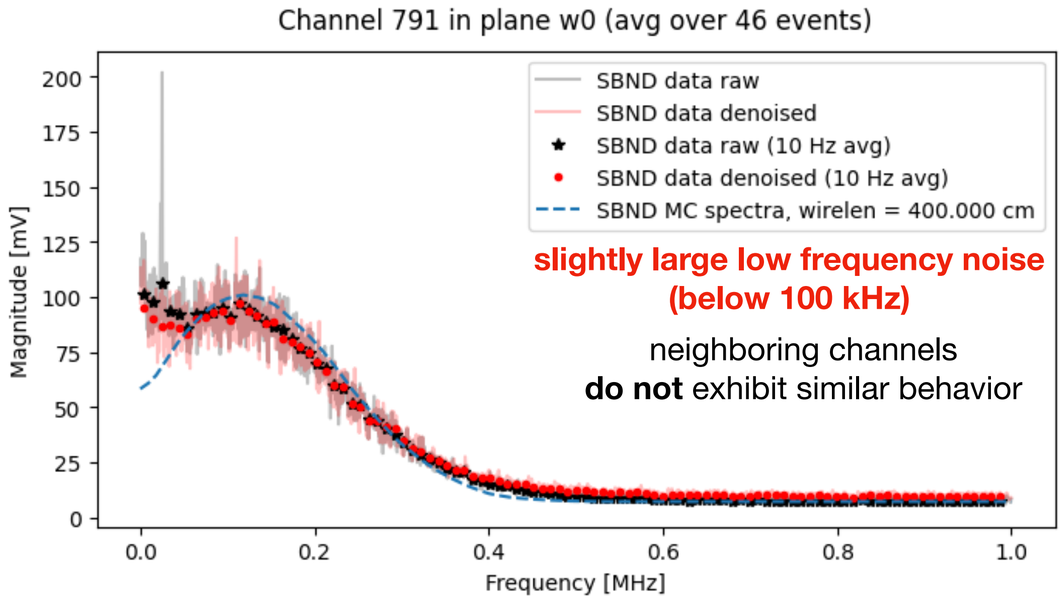

Channel 1758 in plane v0 (avg over 55 events)
SBND data raw
SBND data denoised
SBND data raw (10 Hz avg)
SBND data denoised (10 Hz avg)
SBND MC spectra, wirelen = 159.002 cm
slightly large low frequency noise
(below 100 kHz)
Magnitude [mV]
Frequency [MHz]

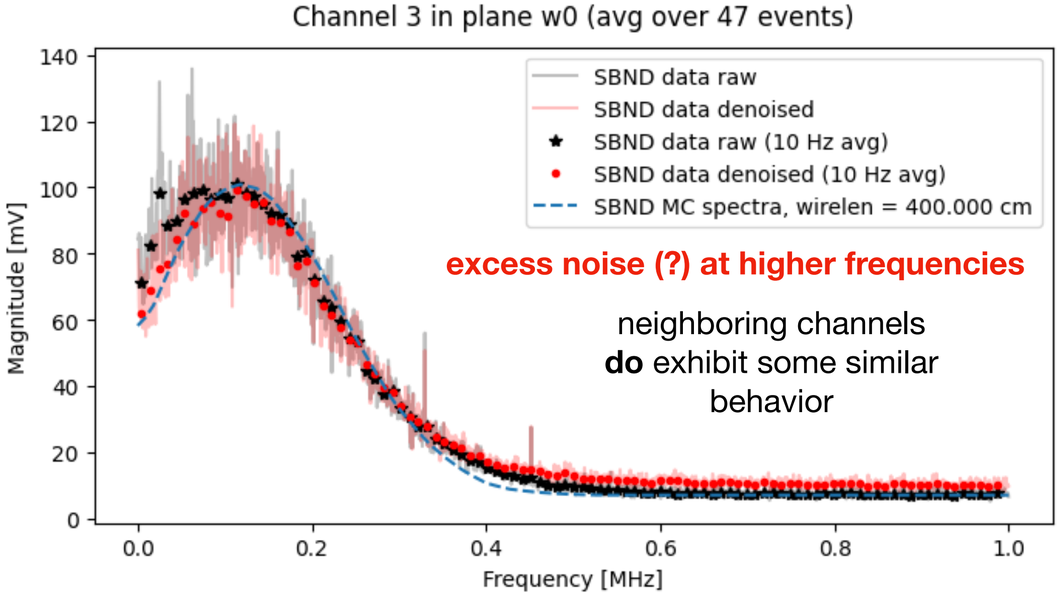

Channel 120 in plane u1 (avg over 85 events)
SBND data raw
SBND data denoised
SBND data raw (10 Hz avg)
SBND data denoised (10 Hz avg)
SBND MC spectra, wirelen = 84.178 cm
excess noise (?) at high frequencies
neighboring channels
do not exhibit similar behavior
Magnitude [mV]
Frequency [MHz]

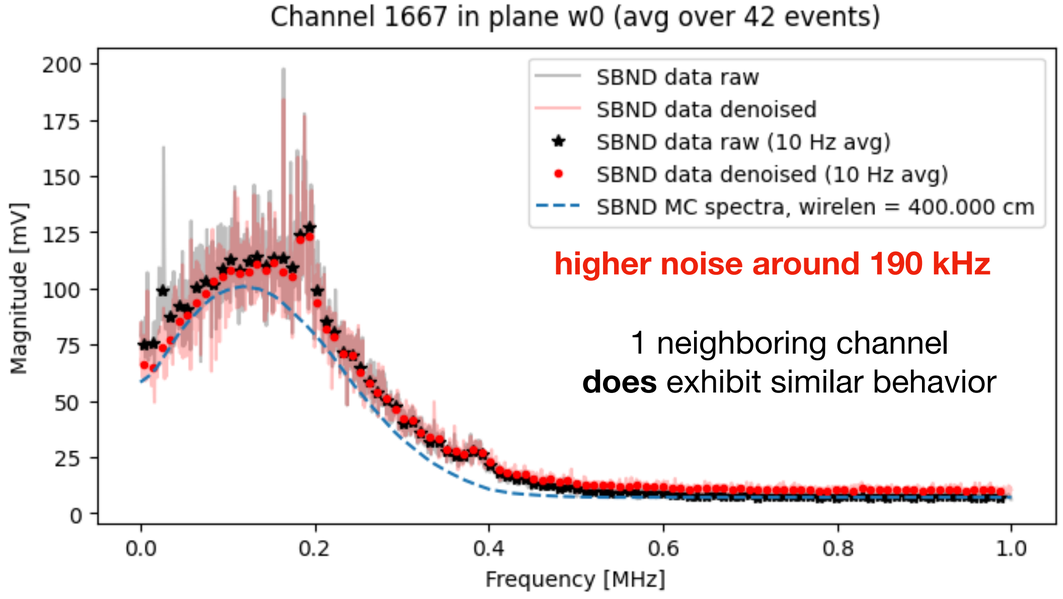

Channel 130 in plane u1 (avg over 84 events)
SBND data raw
SBND data denoised
SBND data raw (10 Hz avg)
SBND data denoised (10 Hz avg)
SBND MC spectra, wirelen = 91.106 cm
slightly large low frequency noise
(below 100 kHz)
Magnitude [mV]
Frequency [MHz]

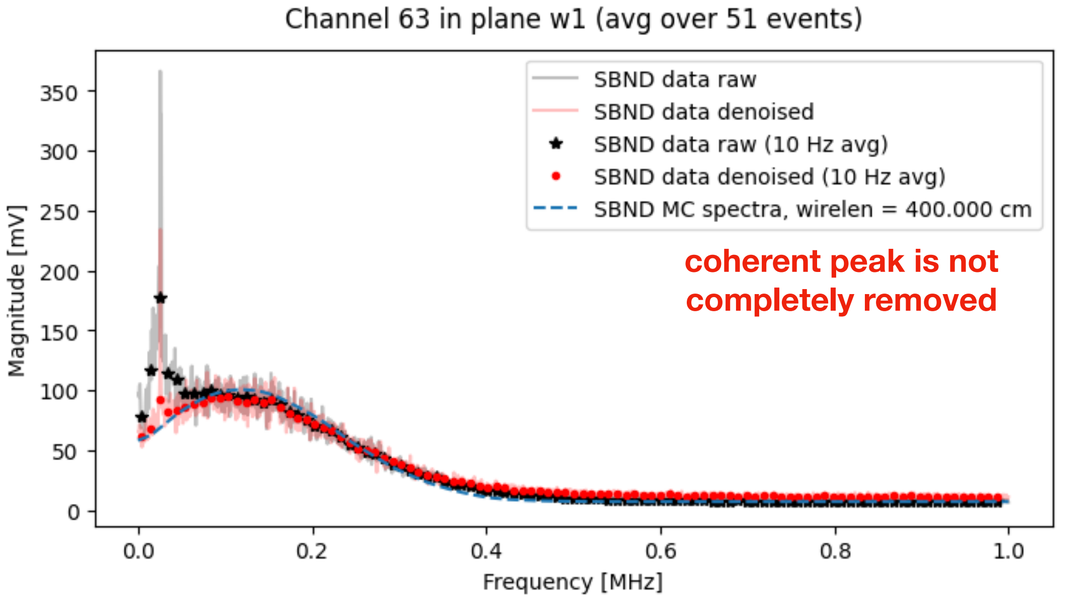

Channel 1131 in plane u1 (avg over 30 events)
SBND data raw
SBND data denoised
SBND data raw (10 Hz avg)
SBND data denoised (10 Hz avg)
SBND MC spectra, wirelen = 578.851 cm
slightly large low frequency noise
(below 100 kHz)
two neighboring channels
do look similar
Magnitude [mV]
Frequency [MHz]


Channel 0 in plane w0 (avg over 60 events)
SBND data raw
SBND data denoised
SBND data raw (10 Hz avg)
SBND data denoised (10 Hz avg)
SBND MC spectra, wirelen = 400.000 cm
excess noise (?) at higher frequencies
neighboring channels
do exhibit some similar
behavior (not all peaks)
Magnitude [mV]
Frequency [MHz]


Channel 791 in plane w0 (avg over 46 events)
SBND data raw
SBND data denoised
SBND data raw (10 Hz avg)
SBND data denoised (10 Hz avg)
SBND MC spectra, wirelen = 400.000 cm
slightly large low frequency noise
(below 100 kHz)
neighboring channels
do not exhibit similar behavior
Magnitude [mV]
Frequency [MHz]

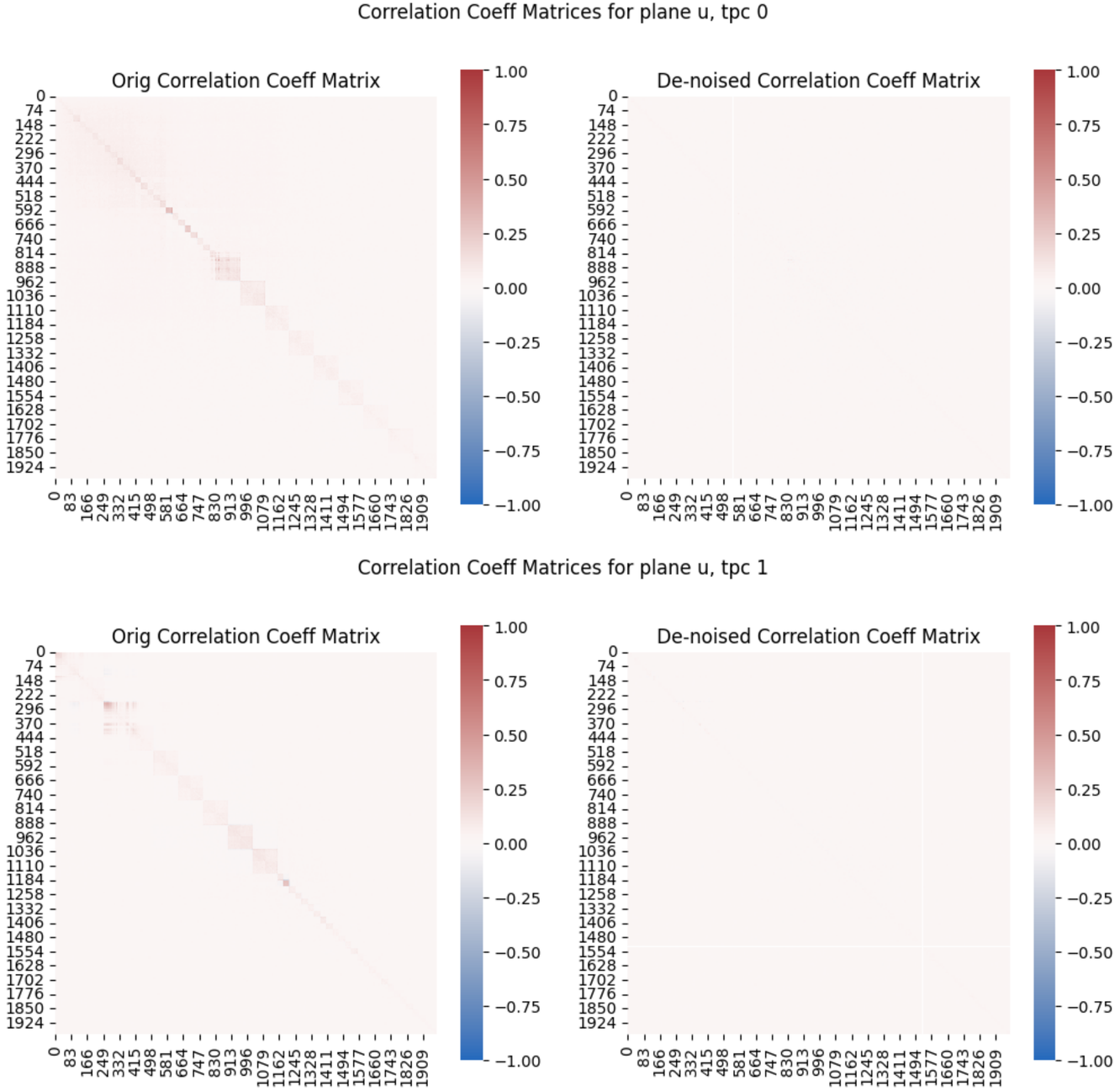

Channel 3 in plane w0 (avg over 47 events)
SBND data raw
SBND data denoised
SBND data raw (10 Hz avg)
SBND data denoised (10 Hz avg)
SBND MC spectra, wirelen = 400.000 cm
excess noise (?) at higher frequencies
neighboring channels
do exhibit some similar
behavior
Magnitude [mV]
Frequency [MHz]

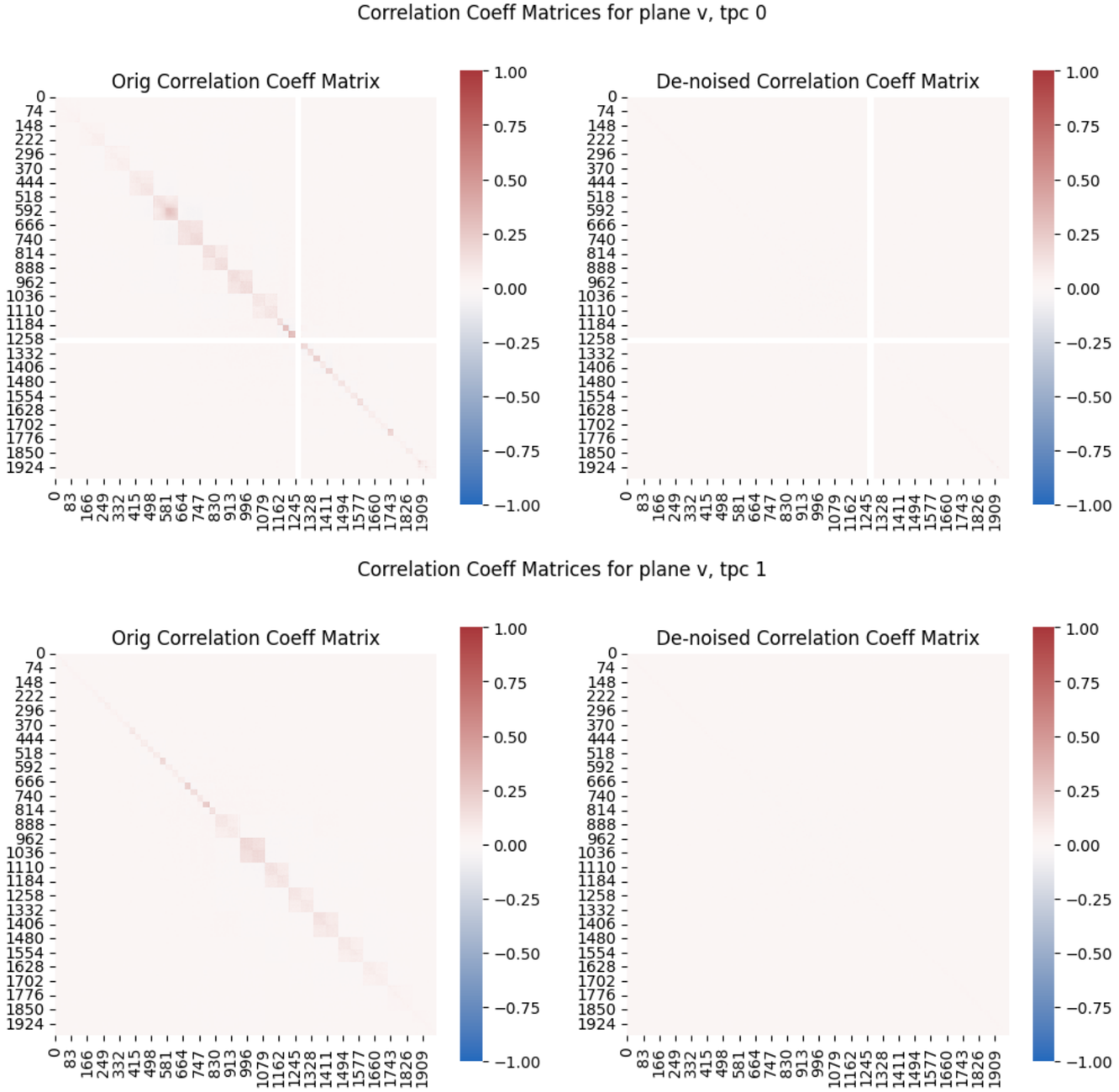

Channel 1667 in plane w0 (avg over 42 events)
SBND data raw
SBND data denoised
SBND data raw (10 Hz avg)
SBND data denoised (10 Hz avg)
SBND MC spectra, wirelen = 400.000 cm
higher noise around 190 kHz
1 neighboring channel
does exhibit similar behavior
Magnitude [mV]
Frequency [MHz]

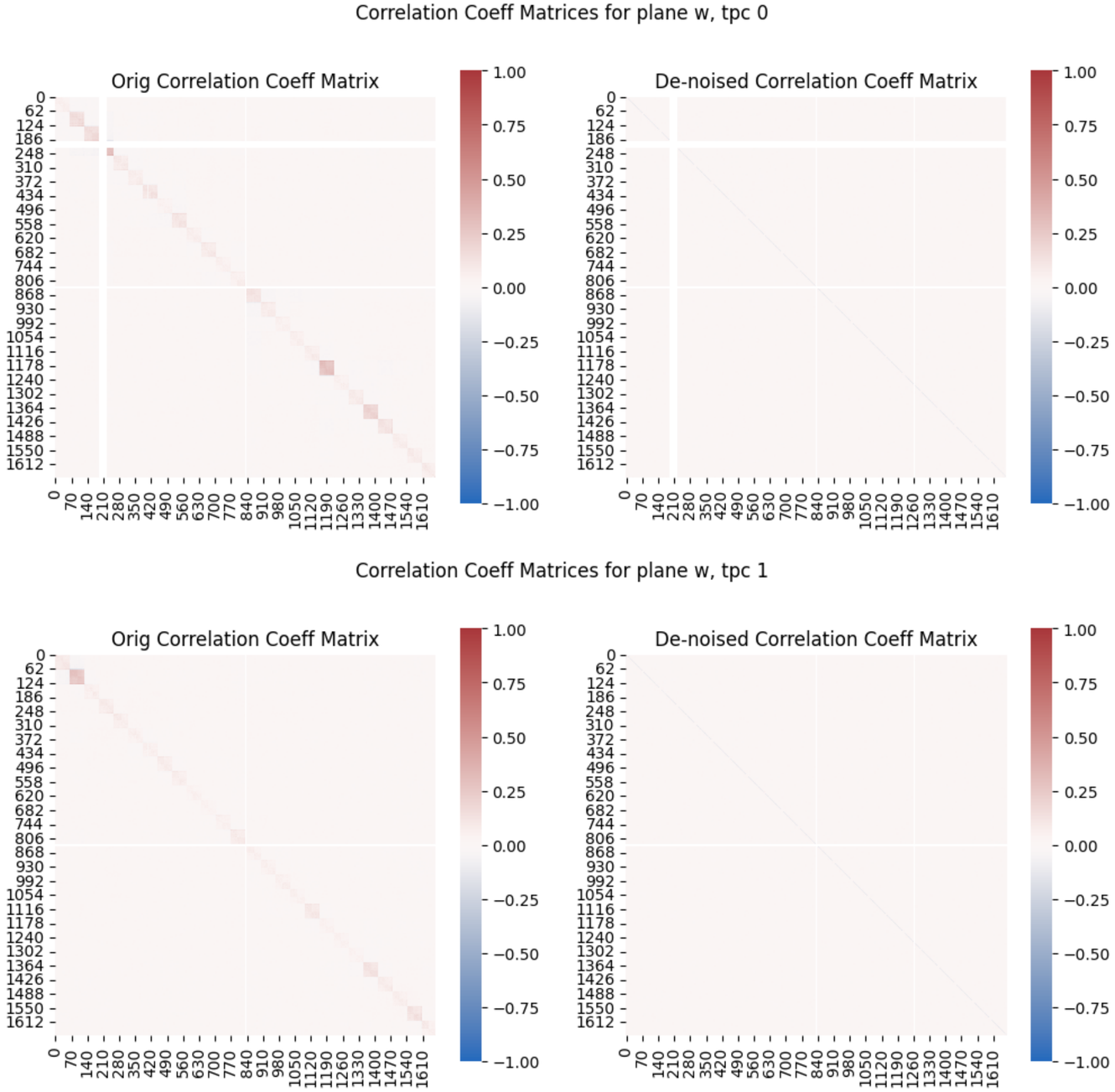


neighboring channels
do not exhibit similar behavior

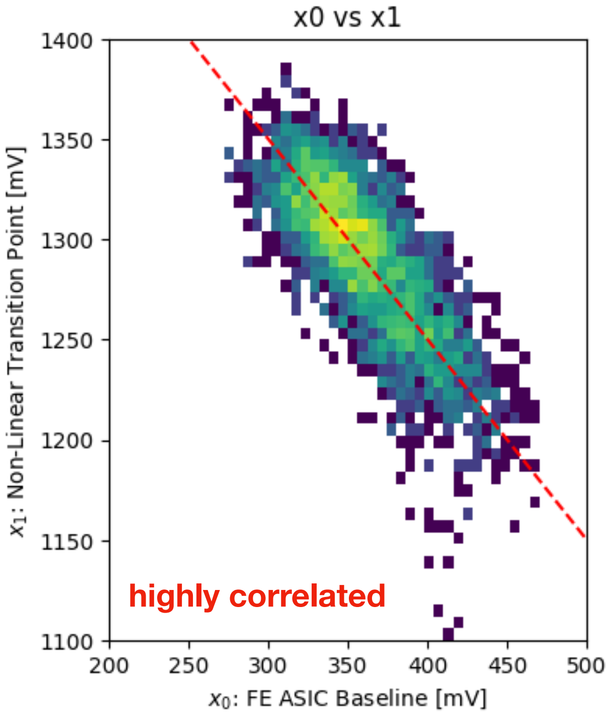
(neighboring channels have similar peak,
but they all have it completely removed)

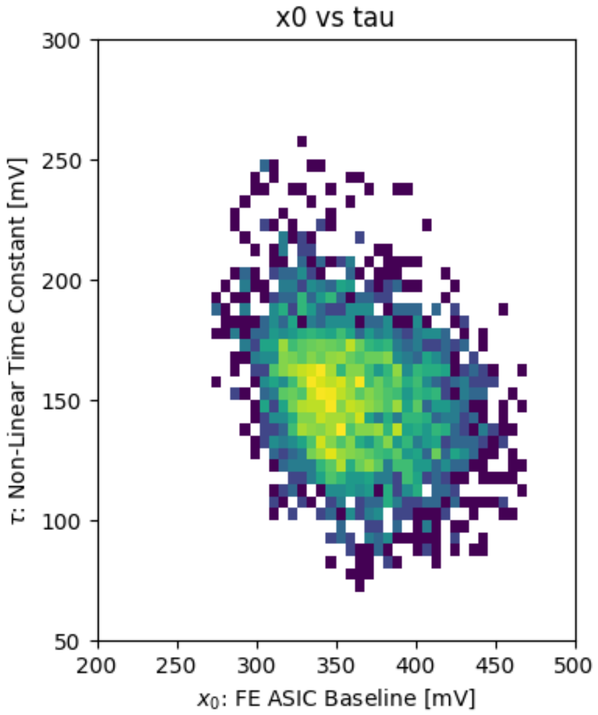

Correlation Coeff Matrices for plane u, tpc 0
Orig Correlation Coeff Matrix
De-noised Correlation Coeff Matrix
Correlation Coeff Matrices for plane u, tpc 1
Orig Correlation Coeff Matrix
De-noised Correlation Coeff Matrix

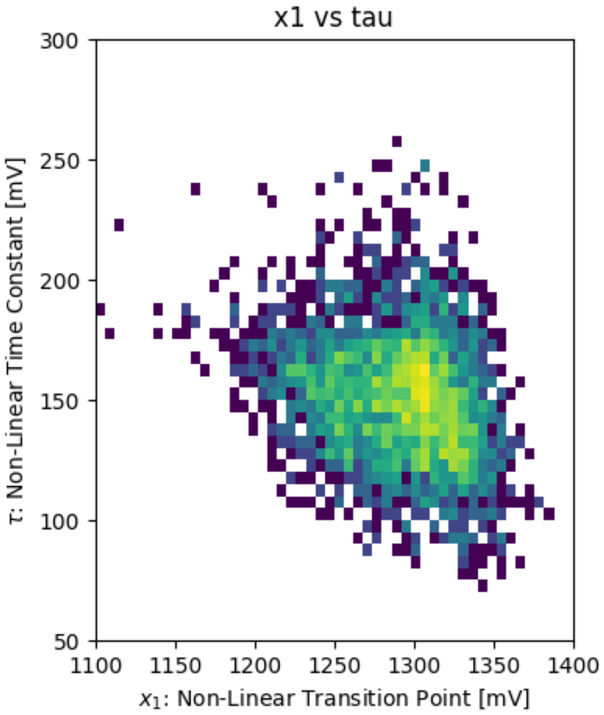

Correlation Coeff Matrices for plane v, tpc 0
Orig Correlation Coeff Matrix
De-noised Correlation Coeff Matrix
Correlation Coeff Matrices for plane v, tpc 1
Orig Correlation Coeff Matrix
De-noised Correlation Coeff Matrix


Correlation Coeff Matrices for plane w, tpc 0
Orig Correlation Coeff Matrix
De-noised Correlation Coeff Matrix
Correlation Coeff Matrices for plane w, tpc 1
Orig Correlation Coeff Matrix
De-noised Correlation Coeff Matrix

fit allowing 3 parameters to float







$$x_1 = 1650 - x_0$$