HiFiPDV:

A High Fidelity Analysis Program for Processing Single Velocity PDV Signals

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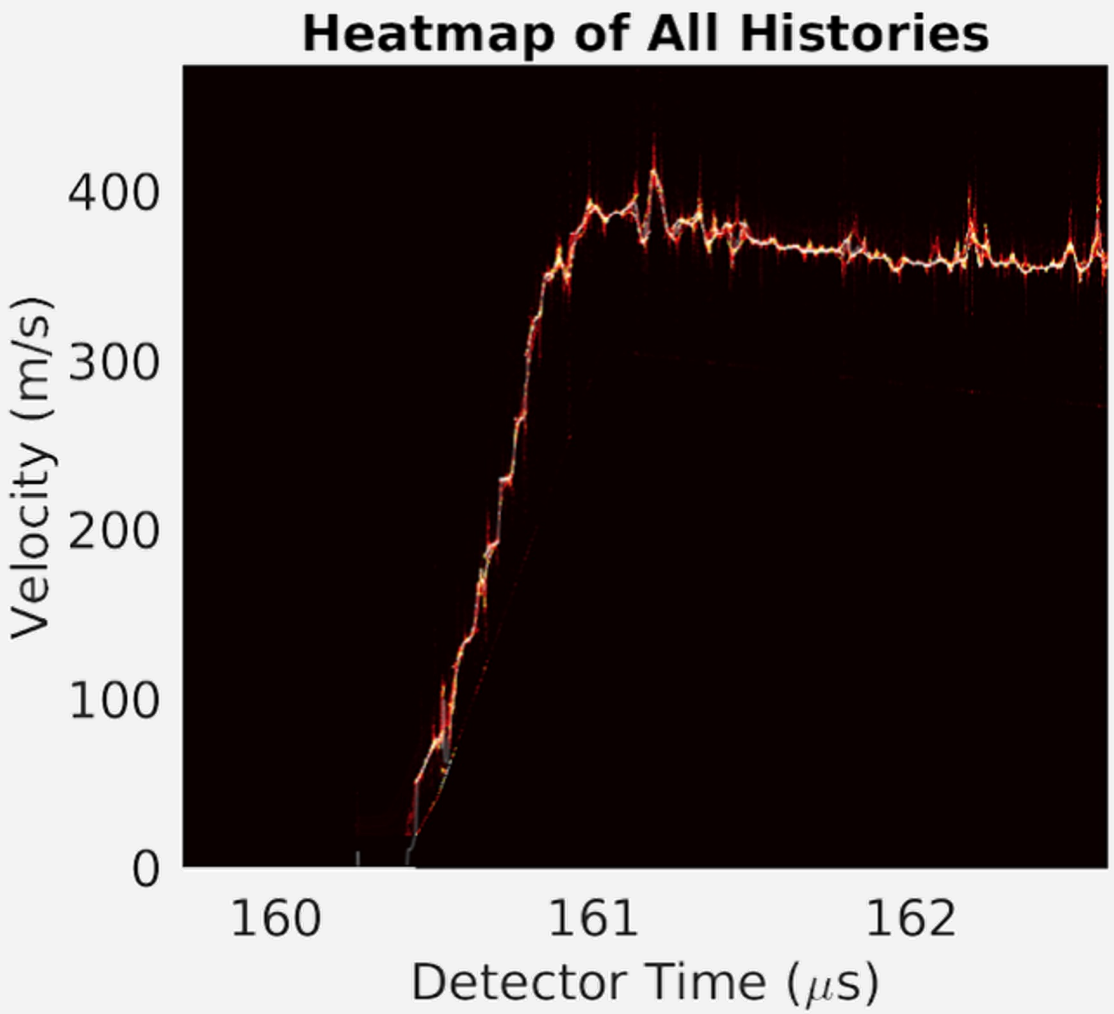
Topics Covered (some will be quick)

- **Why was this code written?**
  - Who is this aimed towards?
  - Where will the code work well and not well?
- **How does the code work?**
- **Positives and negatives of this approach**
- **Areas of improvement for future releases**
- **Acknowledgements**
- **Q&A**



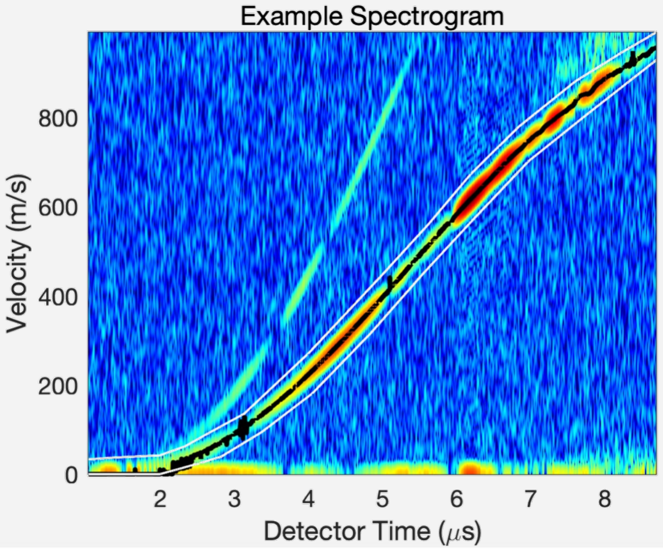
Why was this code written? Who is the audience?

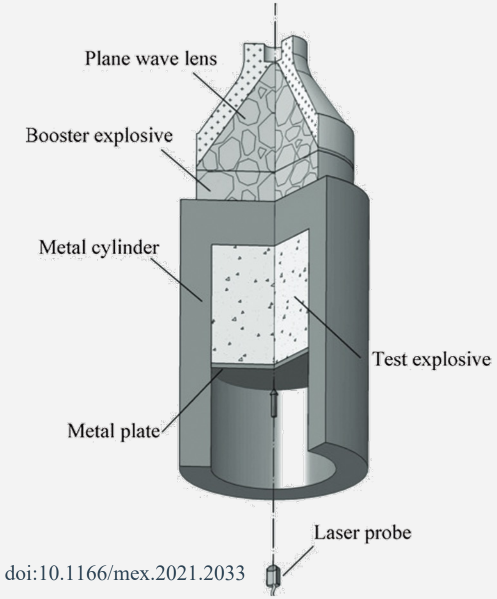
Benefits of this code:

- **Semi-automated.** Minimal user inputs.
- **Consistent** analysis signal-to-signal.
- Calculates **systematic uncertainty.**
- **Simple to use**. Guides user at every step.

Who/What is this code for?

- People that are new to PDV analysis, i.e., graduate students, interns.
- Single velocity signals.
- >300 ns signals.
- Great for high noise:signal ratio.

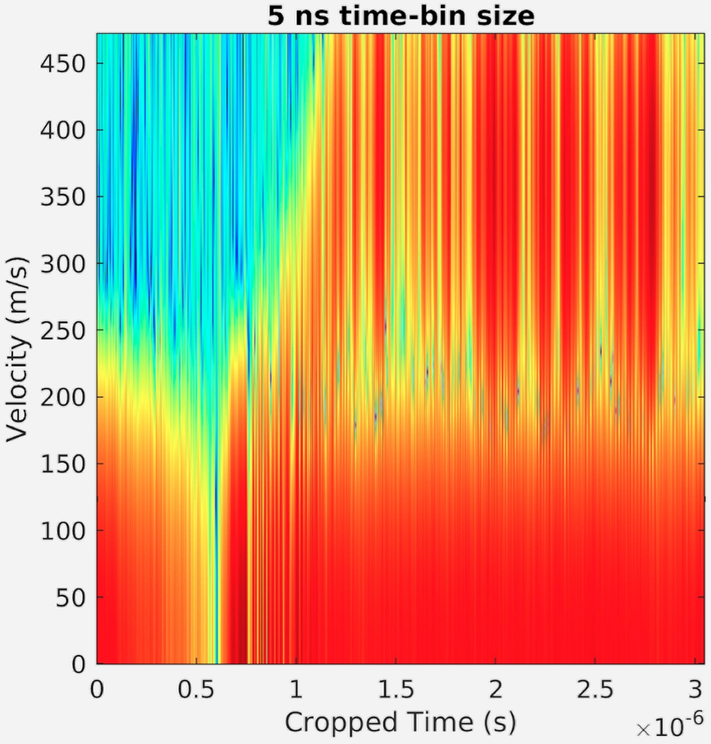




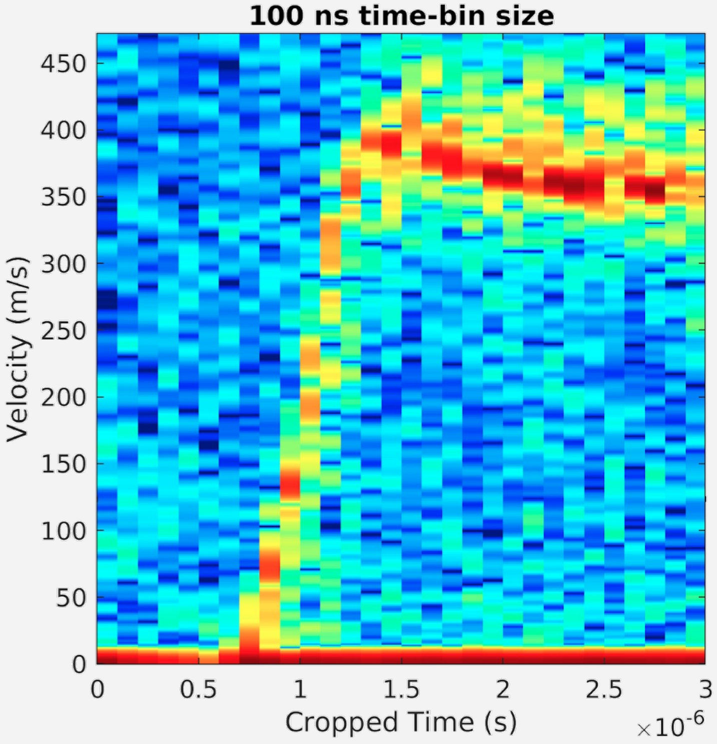
doi:10.1166/mex.2021.2033

There are a lot of knobs in PDV analysis codes

1. Duration length
   a. Time-bin width, or number of data points in calculation
2. Duration overlap
   a. Number of shared data points between adjacent durations
3. Window function
   a. Tapering transform applied to DFT sine waves
4. Peak extraction method
   a. Peak of DFT curve is the output velocity for a time-bin
5. Smoothing



Better **time** resolution



Better **velocity** resolution

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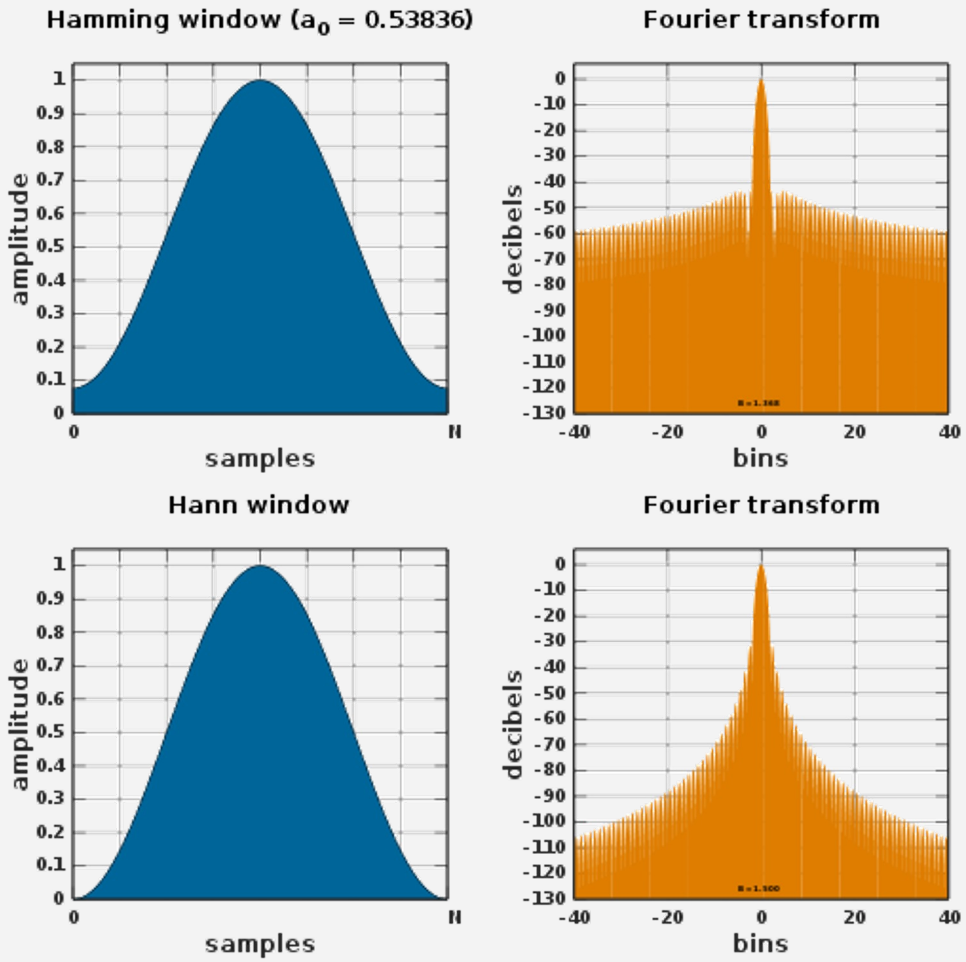

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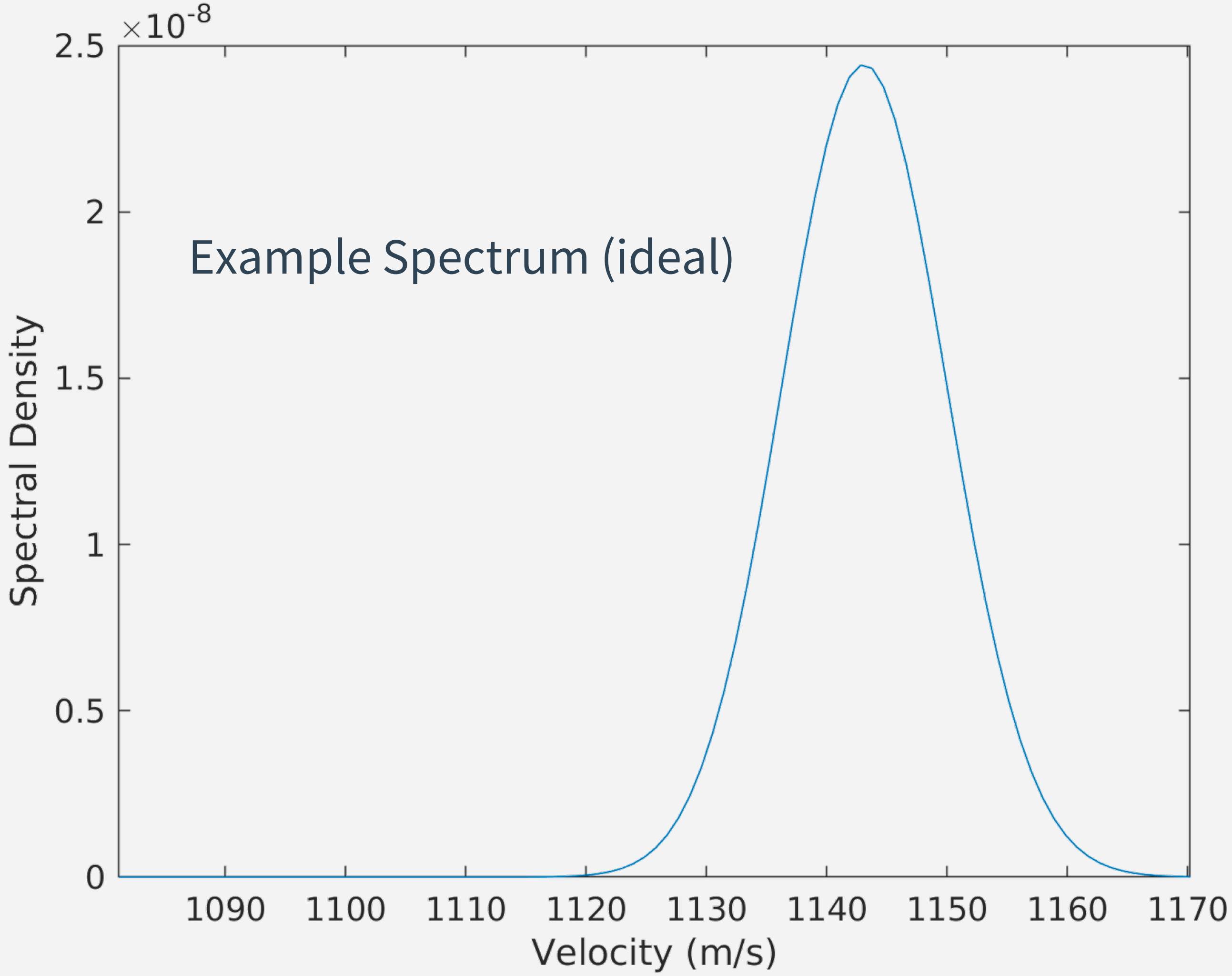

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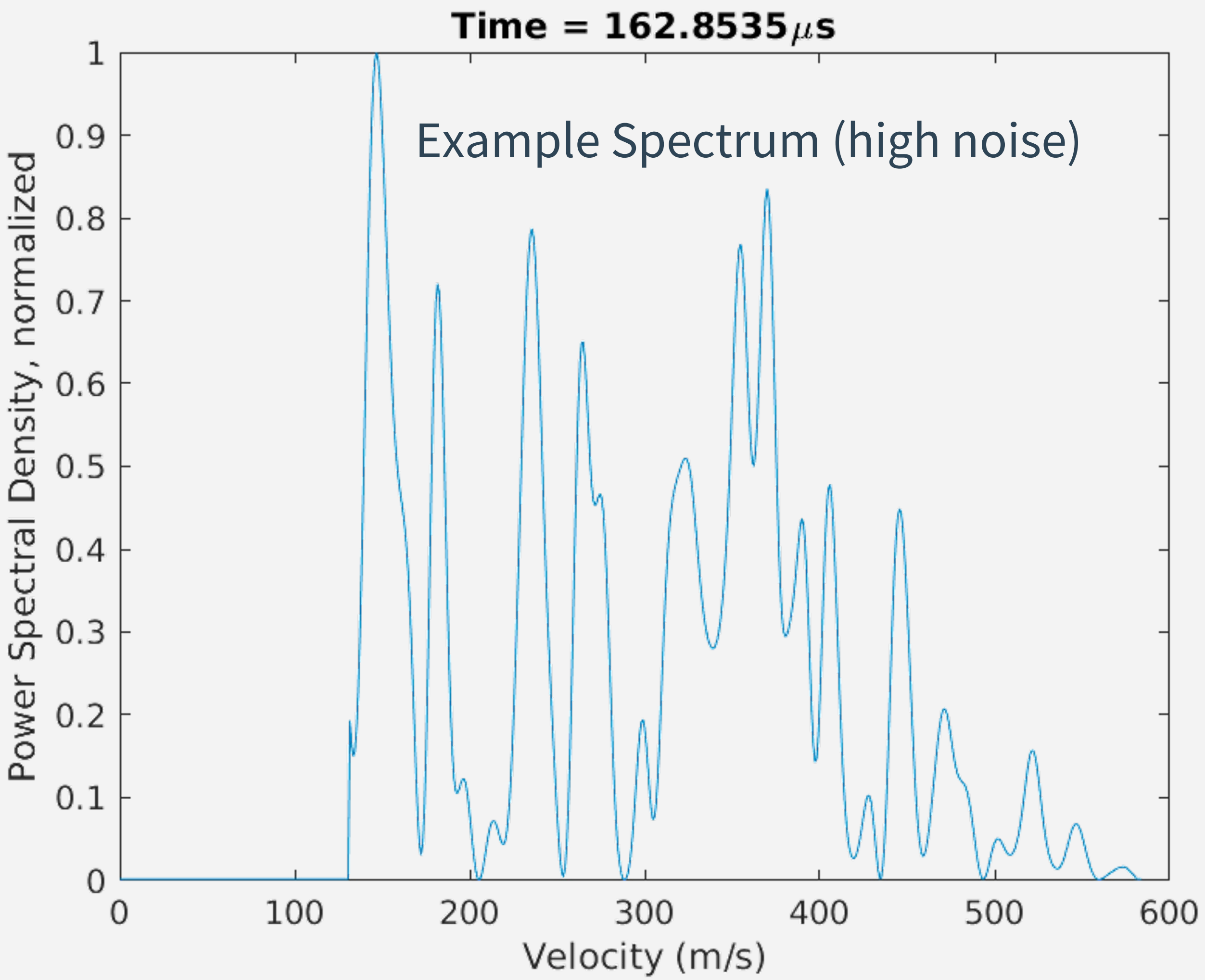
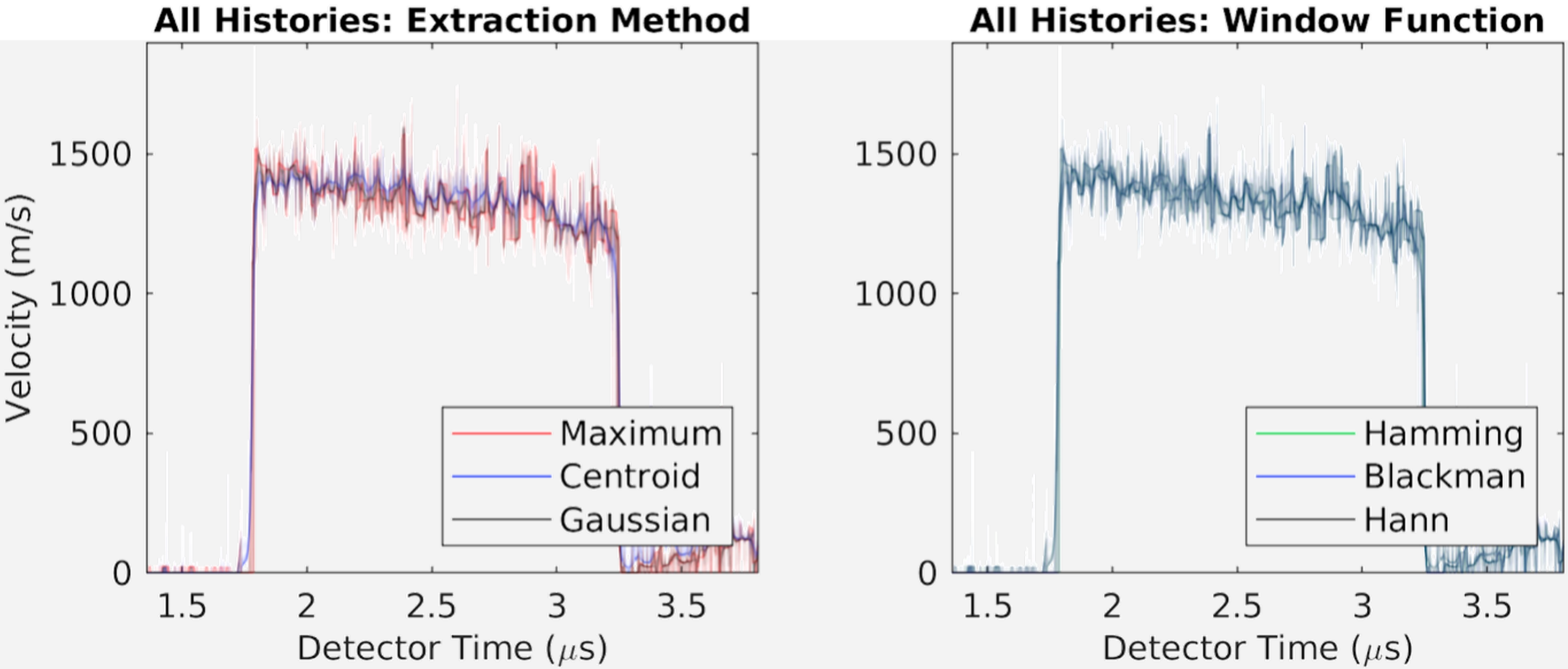


These knobs can significantly change output



All Histories: Extraction Method

All Histories: Window Function

What knob settings are right for your signal?
What's the associated uncertainty?

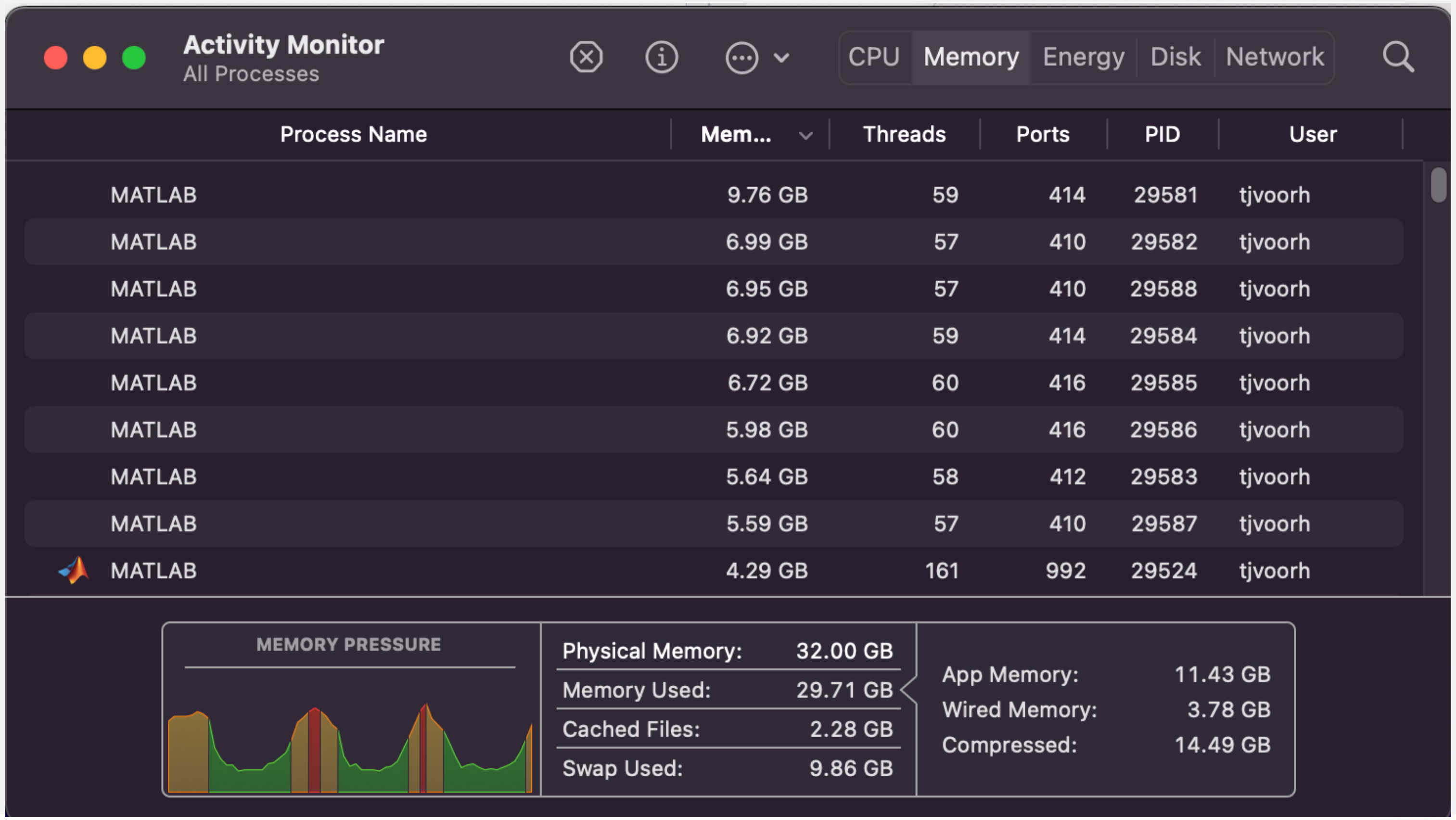
HiFiPDV's Solution: use a broad range of knob settings

Knob inputs:

1. Duration length
   a. 5 to 100 ns
2. Duration overlap
   a. 2.5 ns resolution
3. Window function
   a. Hamming
   b. Hann
   c. Blackman
4. Peak Extraction method
   a. Maximum
   b. Robust centroid
   c. Gaussian
5. Smoothing
   a. Optional (output both)

Downsides to this approach:

1. Computational overhead



Process Name	Mem...	Threads	Ports	PID	User
MATLAB	9.76 GB	59	414	29581	tjvoorh
MATLAB	6.99 GB	57	410	29582	tjvoorh
MATLAB	6.95 GB	57	410	29588	tjvoorh
MATLAB	6.92 GB	59	414	29584	tjvoorh
MATLAB	6.72 GB	60	416	29585	tjvoorh
MATLAB	5.98 GB	60	416	29586	tjvoorh
MATLAB	5.64 GB	58	412	29583	tjvoorh
MATLAB	5.59 GB	57	410	29587	tjvoorh
MATLAB	4.29 GB	161	992	29524	tjvoorh

Physical Memory:	32.00 GB
Memory Used:	29.71 GB
Cached Files:	2.28 GB
Swap Used:	9.86 GB

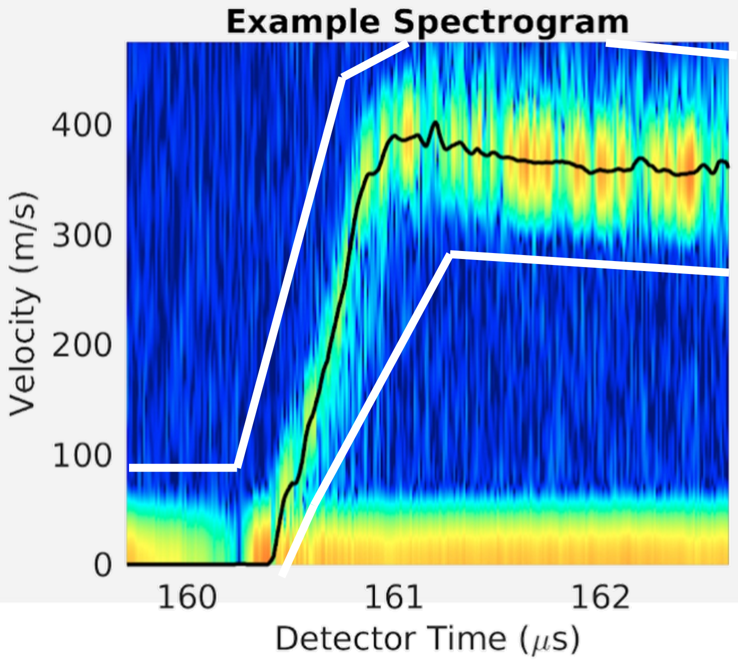
App Memory:	11.43 GB
Wired Memory:	3.78 GB
Compressed:	14.49 GB

How does ***HiFiPDV*** work? (mile high view)

Calculate Spectrograms

1 Time resolution (2.5 ns/pt)
1 Freq. resolution (2^15 bins)
3 Window functions
x20 Duration lengths
60 Spectrograms

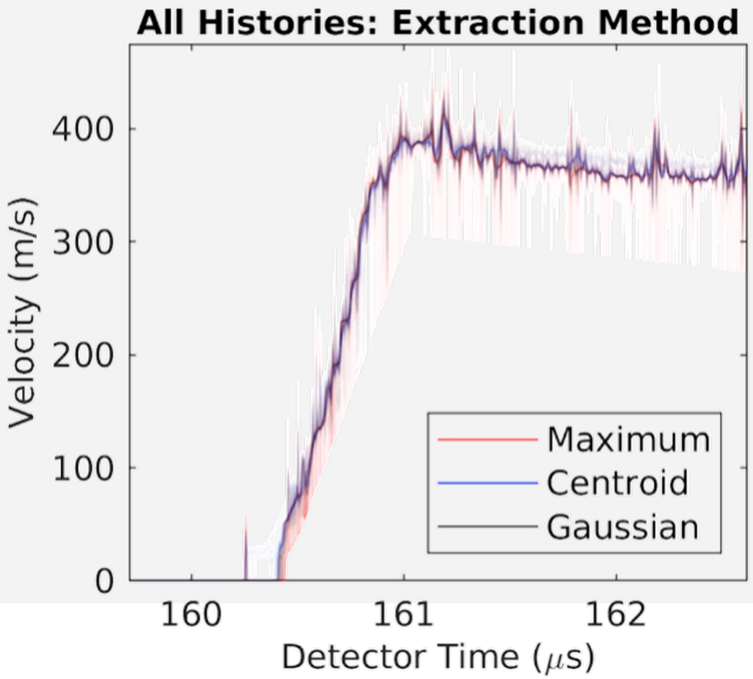
User defines the ROI (white)



Extract Velocities

Max of spectral density
Centroid of spectrum
Gaussian fit to spectrum

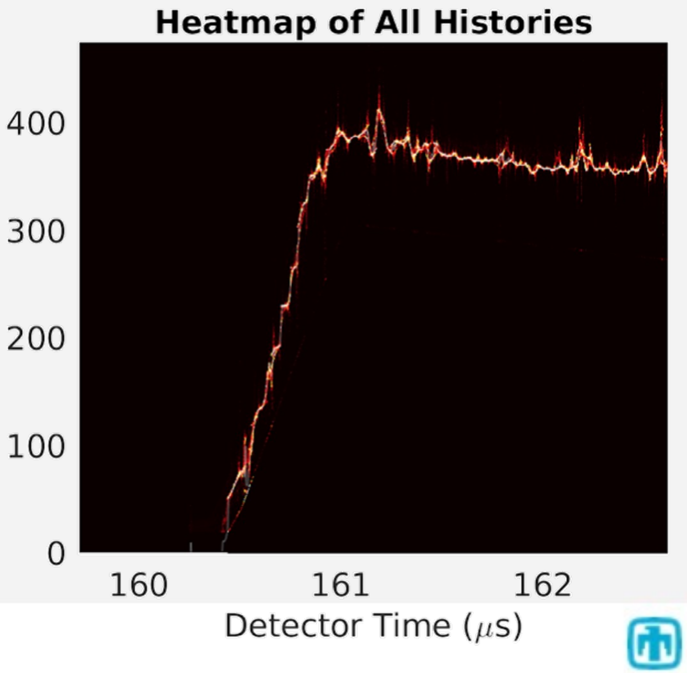
180 velocities per time point



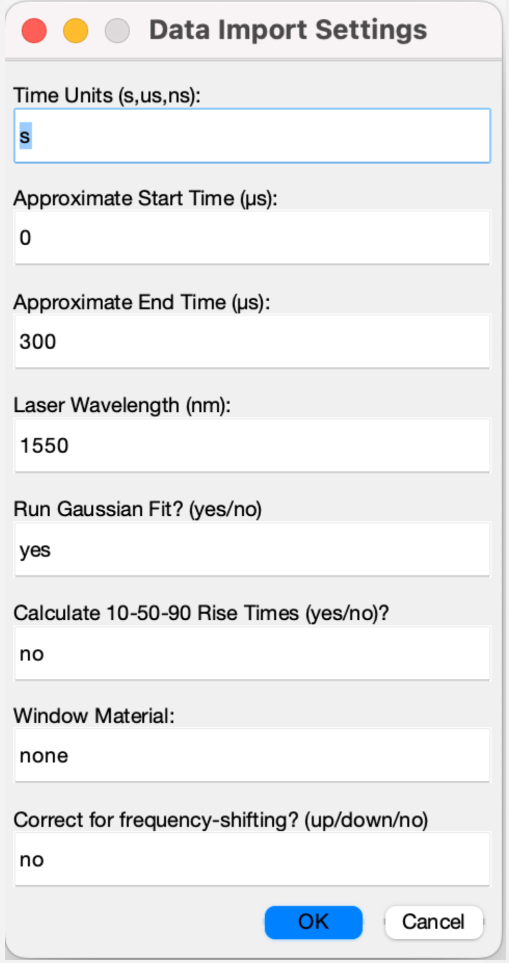
Evaluate Distribution Of Velocities

Collapse histories into a heatmap

Evaluate heatmap distribution at each time-bin for uncertainty analysis



HiFiPDV tries to help guide the user.
It has pop-up prompts at every step of the analysis



Data Import Settings

Time Units (s,us,ns): s

Approximate Start Time (µs): 0

Approximate End Time (µs): 300

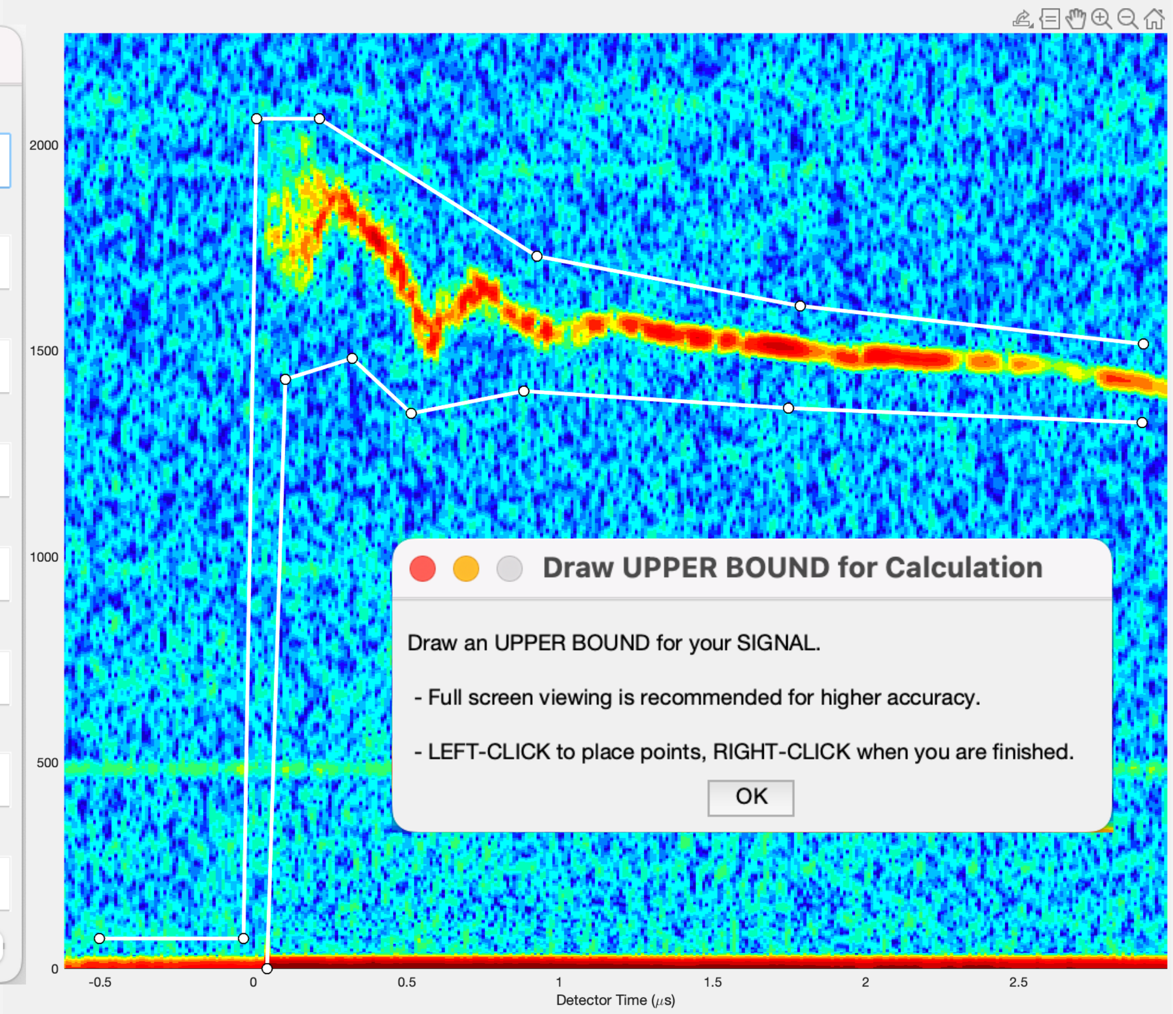
Laser Wavelength (nm): 1550

Run Gaussian Fit? (yes/no): yes

Calculate 10-50-90 Rise Times (yes/no)?: no

Window Material: none

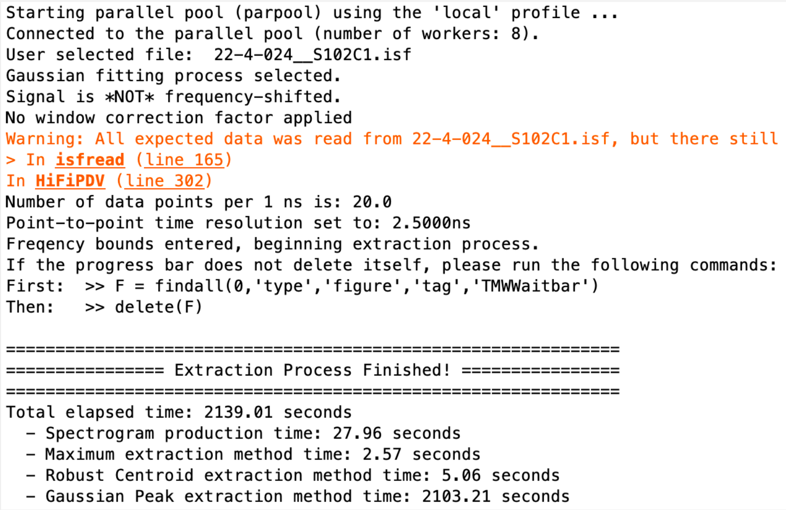
Correct for frequency-shifting? (up/down/no): no



Draw UPPER BOUND for Calculation

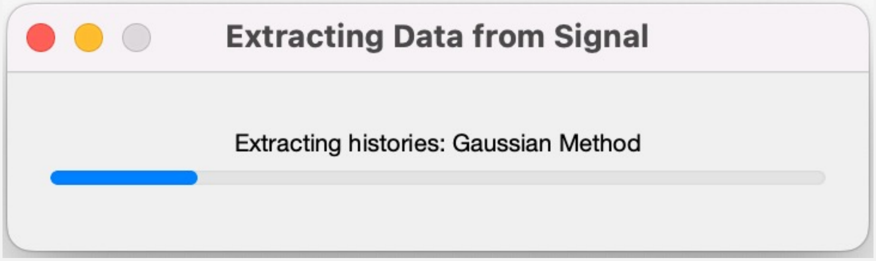
Draw an UPPER BOUND for your SIGNAL.

- Full screen viewing is recommended for higher accuracy.
- LEFT-CLICK to place points, RIGHT-CLICK when you are finished.



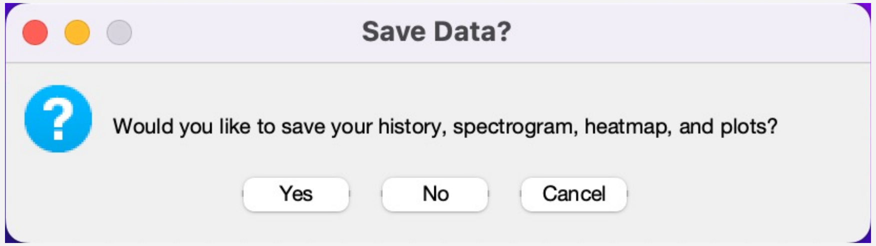
```
Starting parallel pool (parpool) using the 'local' profile ...
Connected to the parallel pool (number of workers: 8).
User selected file:  22-4-024__S102C1.isf
Gaussian fitting process selected.
Signal is *NOT* frequency-shifted.
No window correction factor applied
Warning: All expected data was read from 22-4-024__S102C1.isf, but there still
> In isfread (line 165)
In HiFiPDV (line 302)
Number of data points per 1 ns is: 20.0
Point-to-point time resolution set to: 2.5000ns
Freqency bounds entered, beginning extraction process.
If the progress bar does not delete itself, please run the following commands:
First:  >> F = findall(0,'type','figure','tag','TMWWaitbar')
Then:   >> delete(F)

==============================================================
================ Extraction Process Finished! ================
==============================================================
Total elapsed time: 2139.01 seconds
  - Spectrogram production time: 27.96 seconds
  - Maximum extraction method time: 2.57 seconds
  - Robust Centroid extraction method time: 5.06 seconds
  - Gaussian Peak extraction method time: 2103.21 seconds
```



Extracting Data from Signal

Extracting histories: Gaussian Method



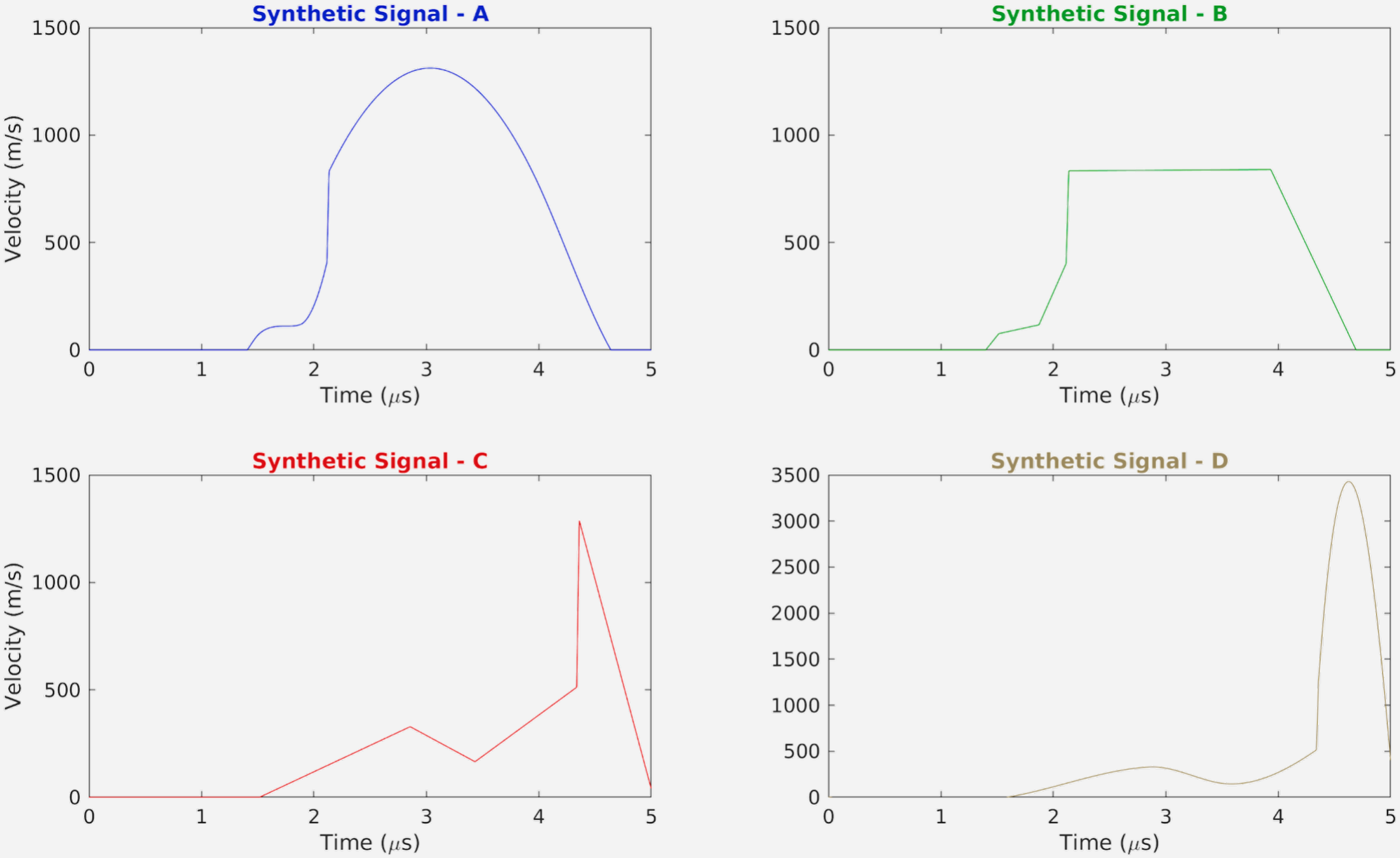
Save Data?

Would you like to save your history, spectrogram, heatmap, and plots?

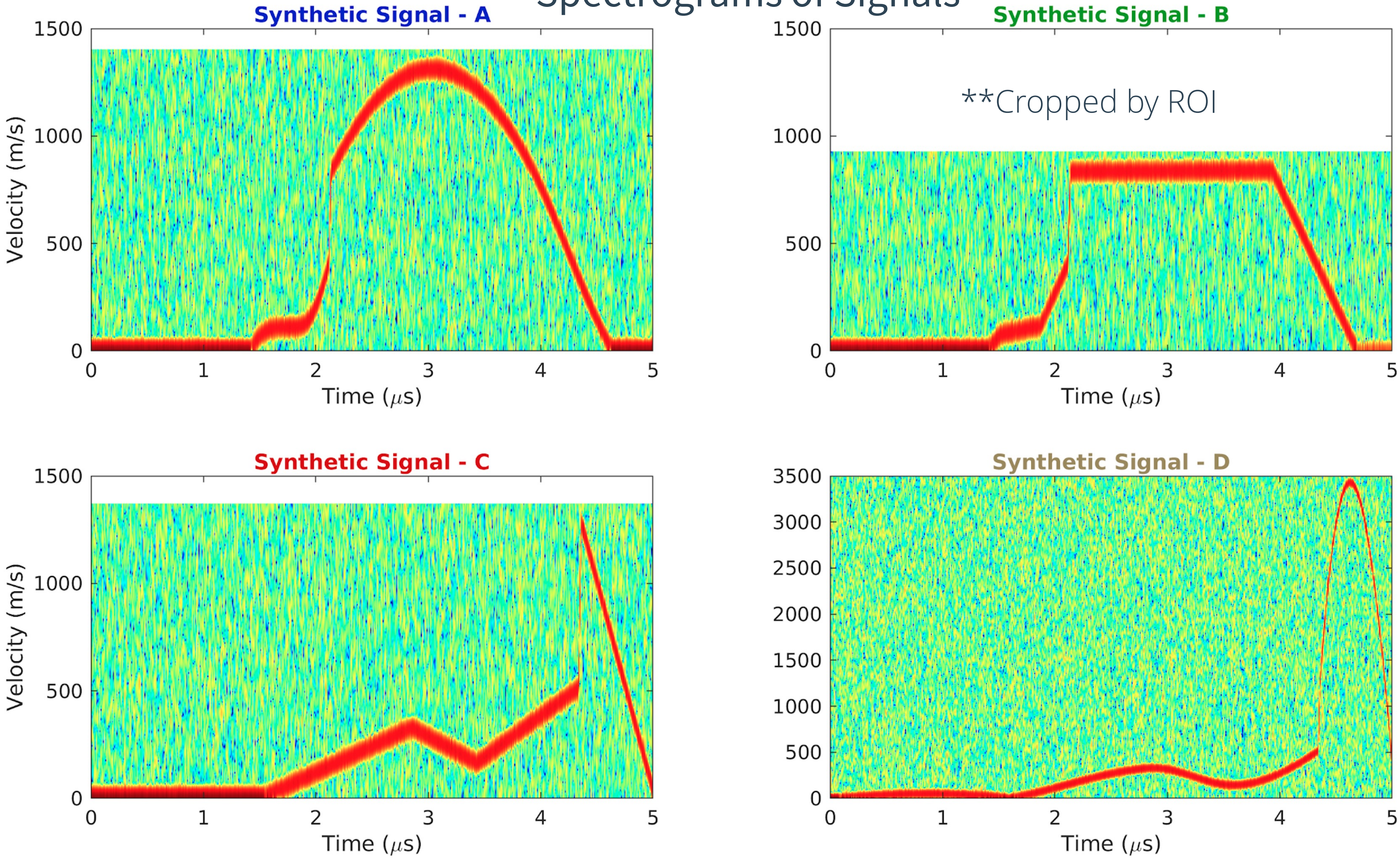
How well can ***HiFiPDV*** reproduce synthetic data?

Signal Parameters:

- Noise:Signal = 10
- Sample Rate = 4e10
- Various accelerations
- Jagged or curved

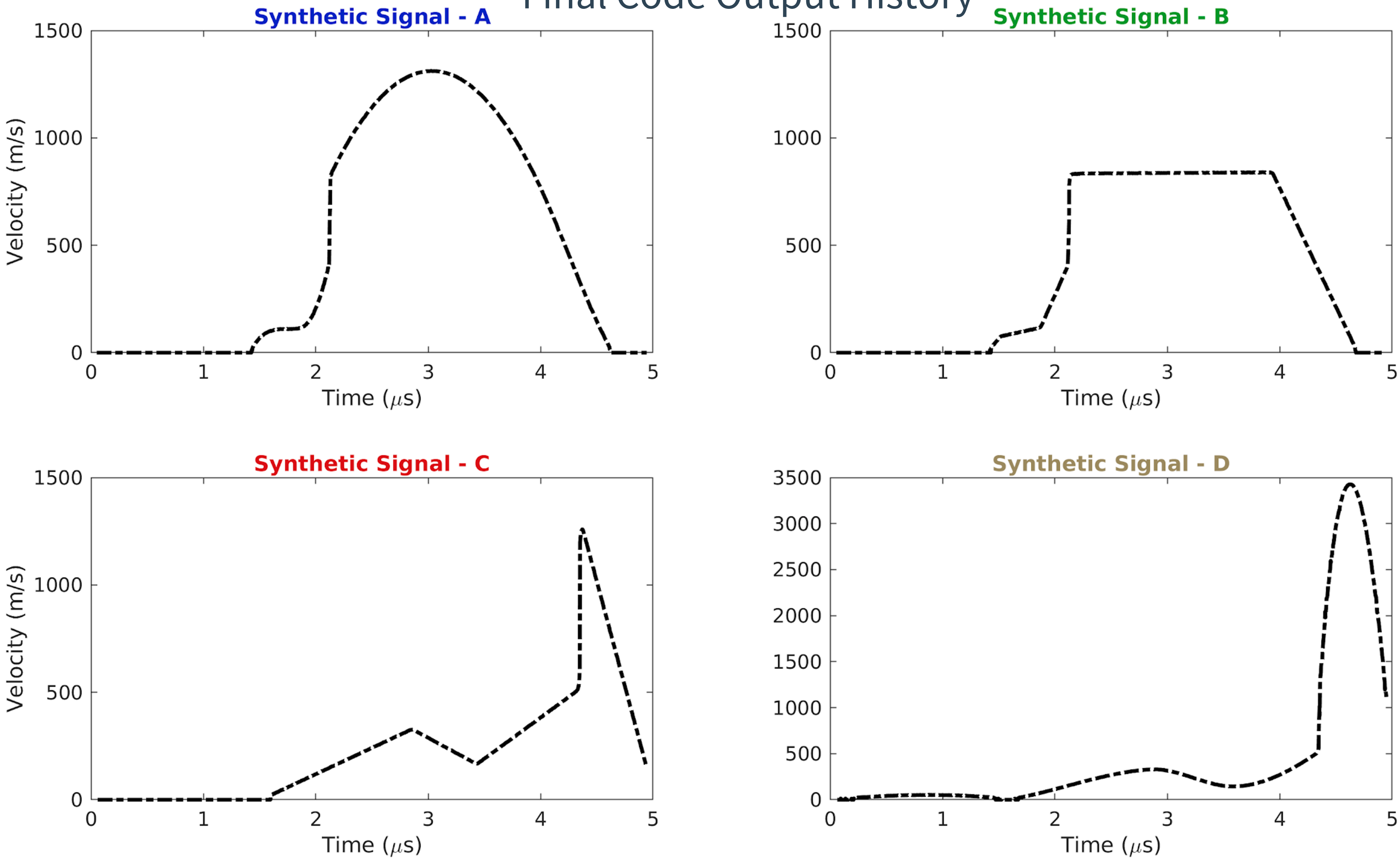


Spectrograms of Signals

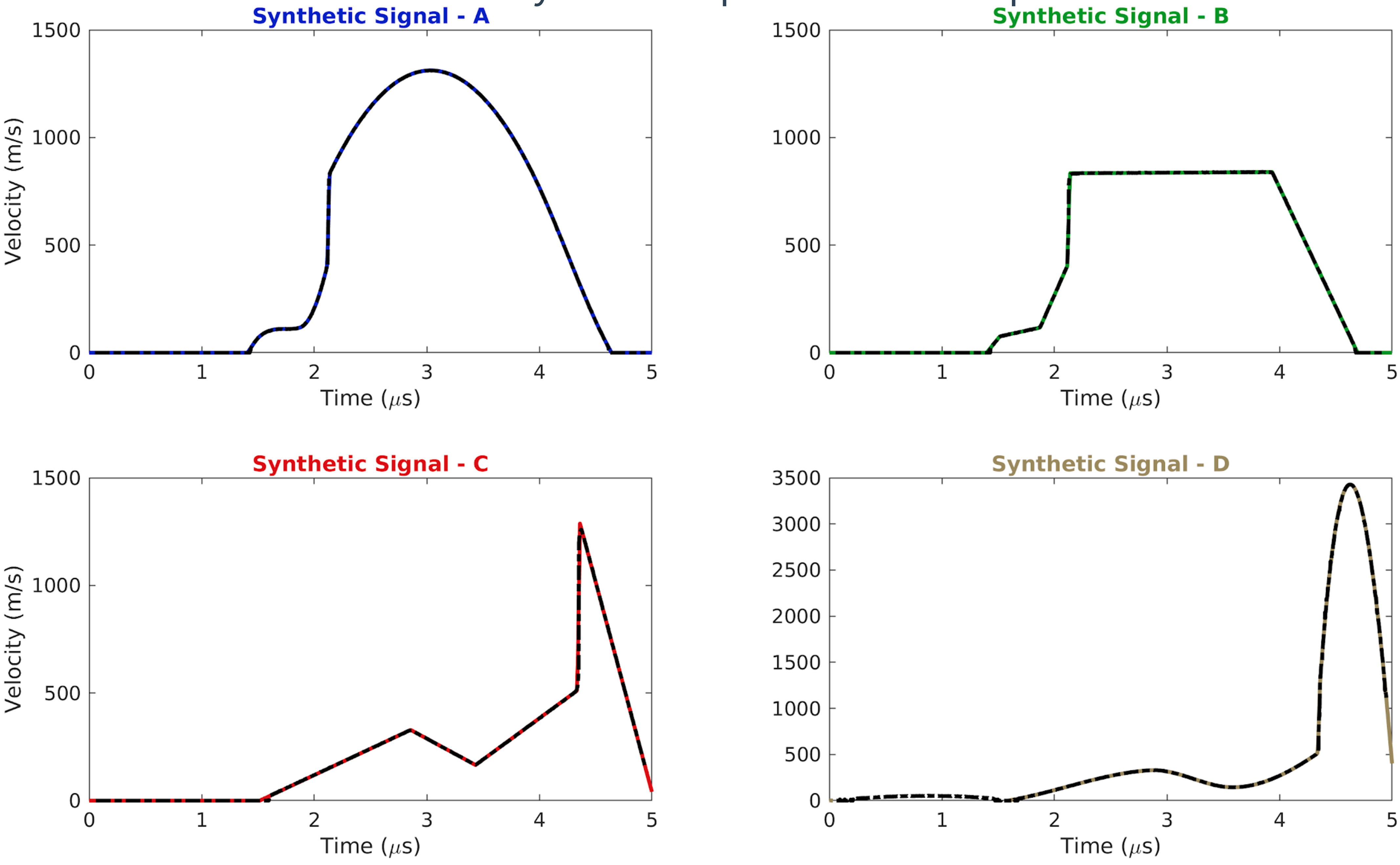


**Cropped by ROI

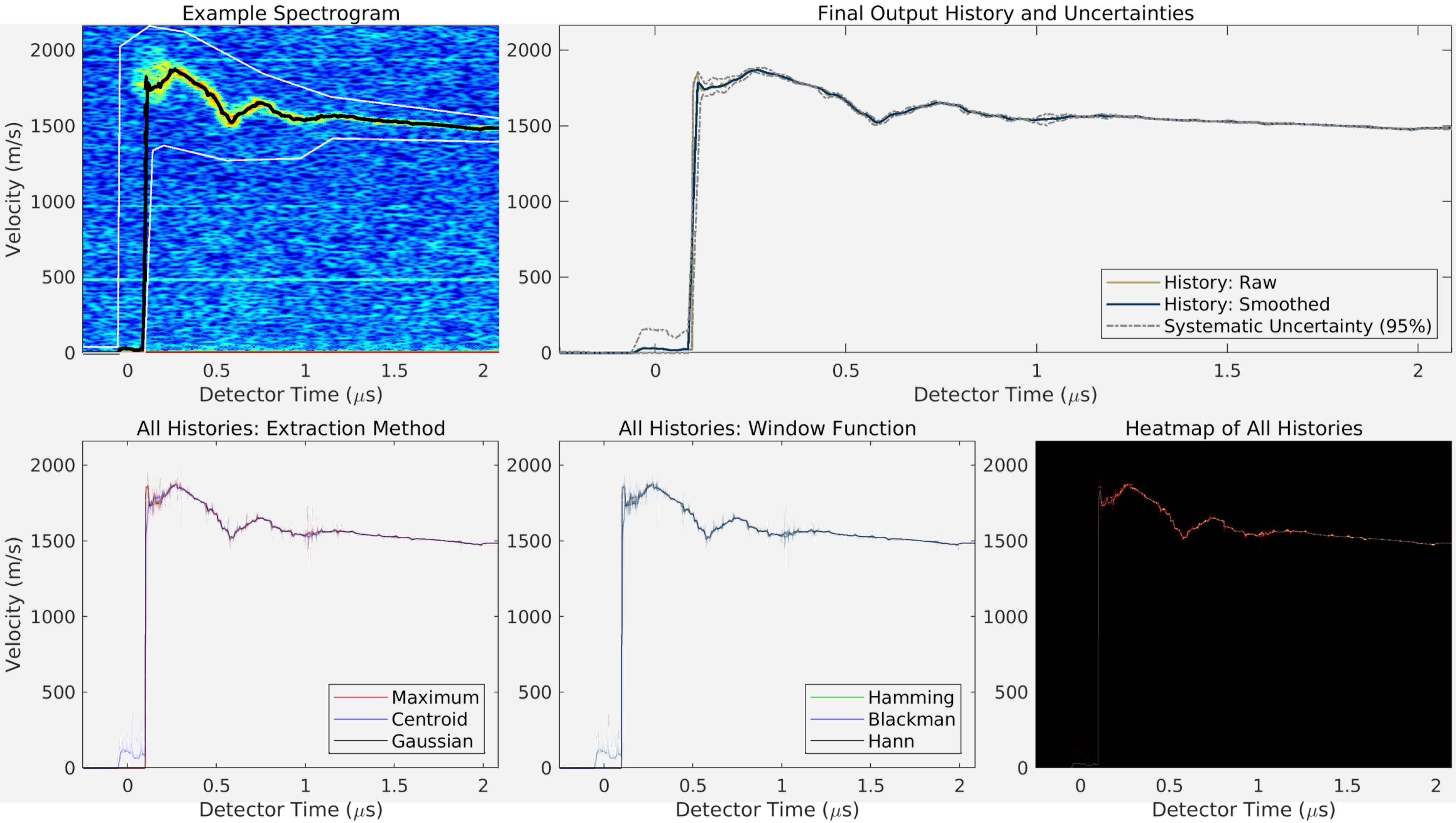
Final Code Output History



Overlaid Synthetic Input vs. Code Output

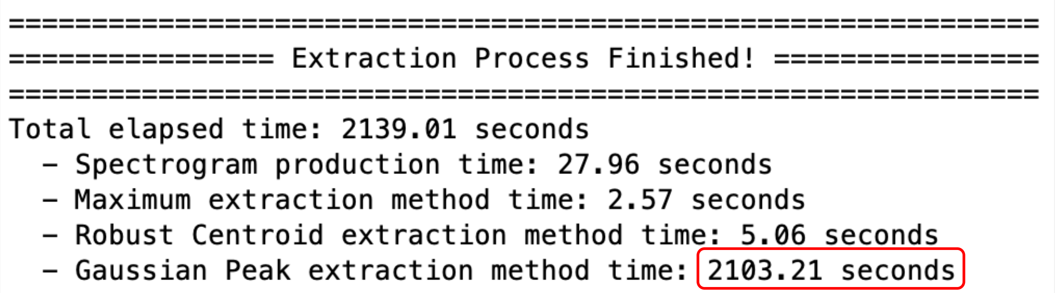


Applied to real data:
Cu @ 2.39 km/s into Mo-PFO RMI



Areas of improvement

- Computational overhead
- Speed up Gaussian fit
  - Gaussian fitting accounts for ~95-99% of code run time
- Better spectrogram cropping
- More output freedom
  - Choose your spectrogram
  - Choose your colormaps
- Reduce toolbox usage



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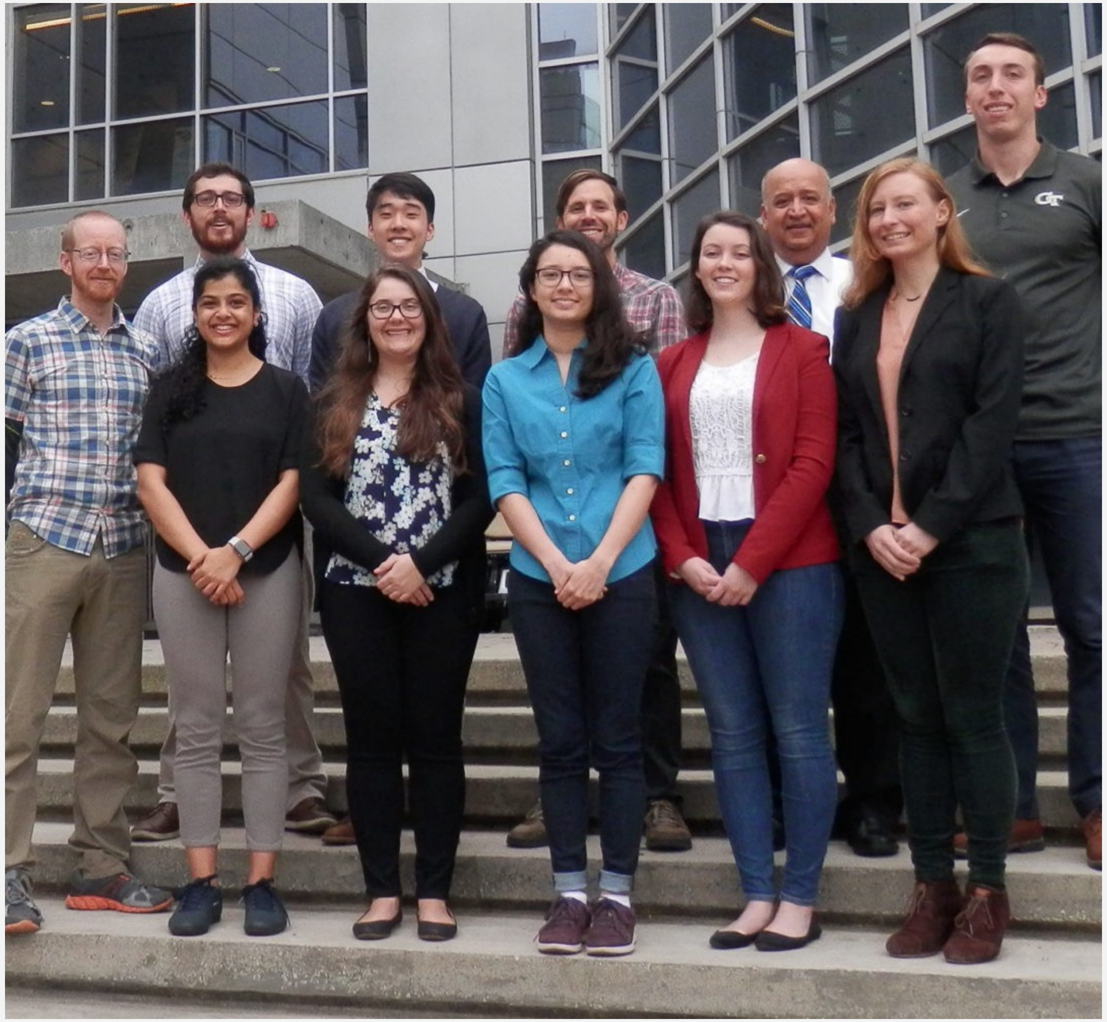
Acknowledgements

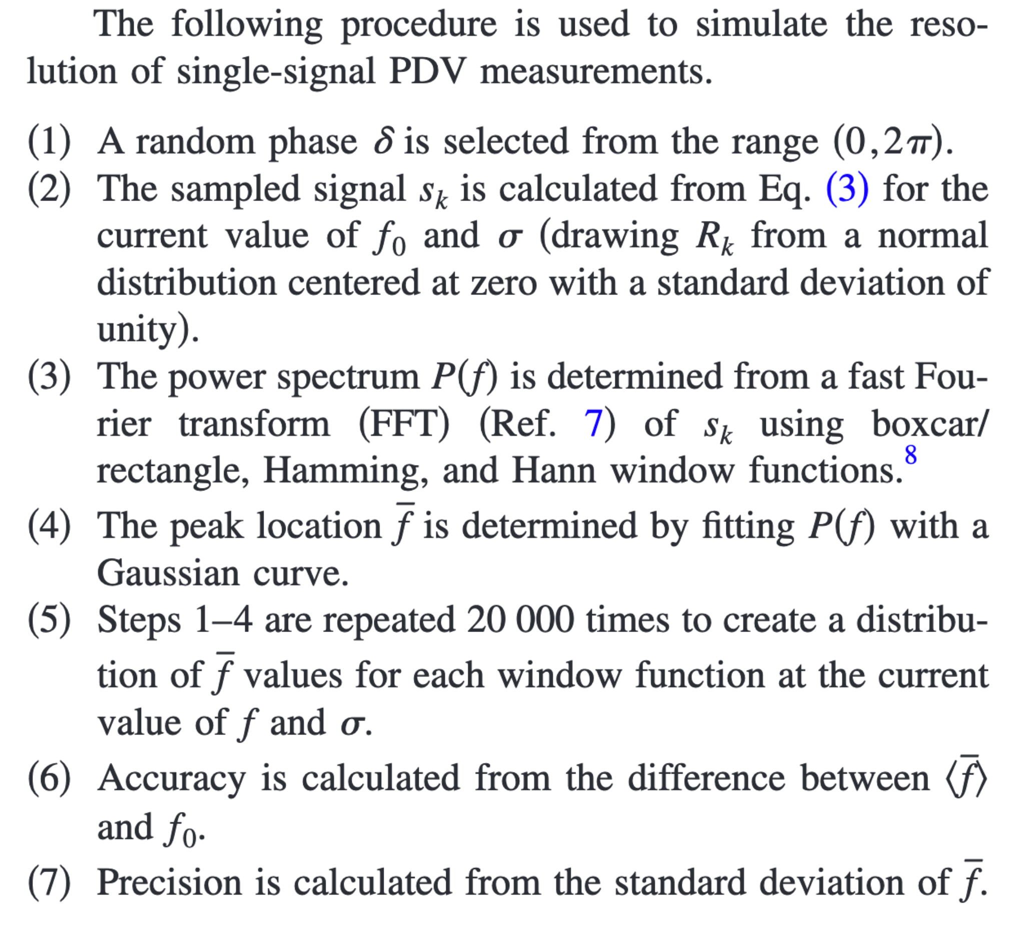
- Code Testers:
  - Georgia Tech: Greg Kennedy, Andrew Boddorff, Katie Koube, Keara Frawley, Ben Zussman, and the whole HSR lab
  - Sandia Natl Lab: Stacy Guo
- Advice and Support:
  - Sandia Natl Lab: Dan Dolan, Sheri Payne
  - Georgia Tech: Greg Kennedy, Naresh Thadhani
  - Los Alamos Natl Lab: John Lang
- Example Data:
  - Georgia Tech HSR Lab
  - Dynamic Compression Sector (DCS)



Thank you!
tjvoorh@sandia.gov

Inspired by Dan Dolan's "Accuracy and Precision in PDV" Influenced by SIRHEN, PDV_Display, and PlotData

Dan's methodology: 10.1063/1.3429257



The following procedure is used to simulate the resolution of single-signal PDV measurements.

(1) A random phase δ is selected from the range $(0,2\pi)$.

(2) The sampled signal s_k is calculated from Eq. (3) for the current value of f_0 and σ (drawing R_k from a normal distribution centered at zero with a standard deviation of unity).

(3) The power spectrum $P(f)$ is determined from a fast Fourier transform (FFT) (Ref. 7) of s_k using boxcar/rectangle, Hamming, and Hann window functions.[8]

(4) The peak location $\bar{f}$ is determined by fitting $P(f)$ with a Gaussian curve.

(5) Steps 1–4 are repeated 20 000 times to create a distribution of $\bar{f}$ values for each window function at the current value of f and σ.

(6) Accuracy is calculated from the difference between $\langle \bar{f} \rangle$ and f_0.

(7) Precision is calculated from the standard deviation of $\bar{f}$.

How does the code work?

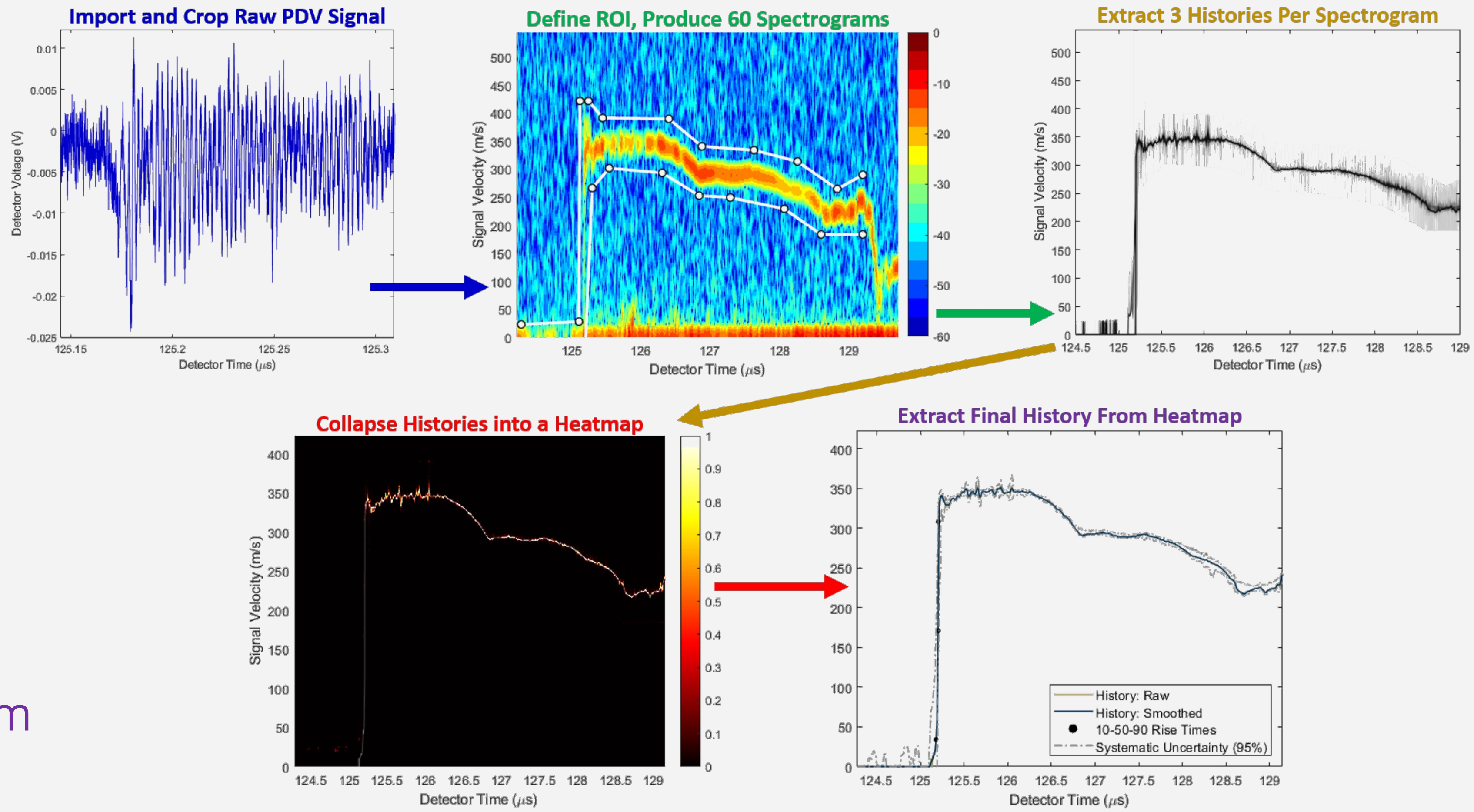
1. Import and rough crop

2. Spectrograms & Cropping:
   a. Generates spectrograms
   b. Users define ROI
   c. Crops specs to ROI

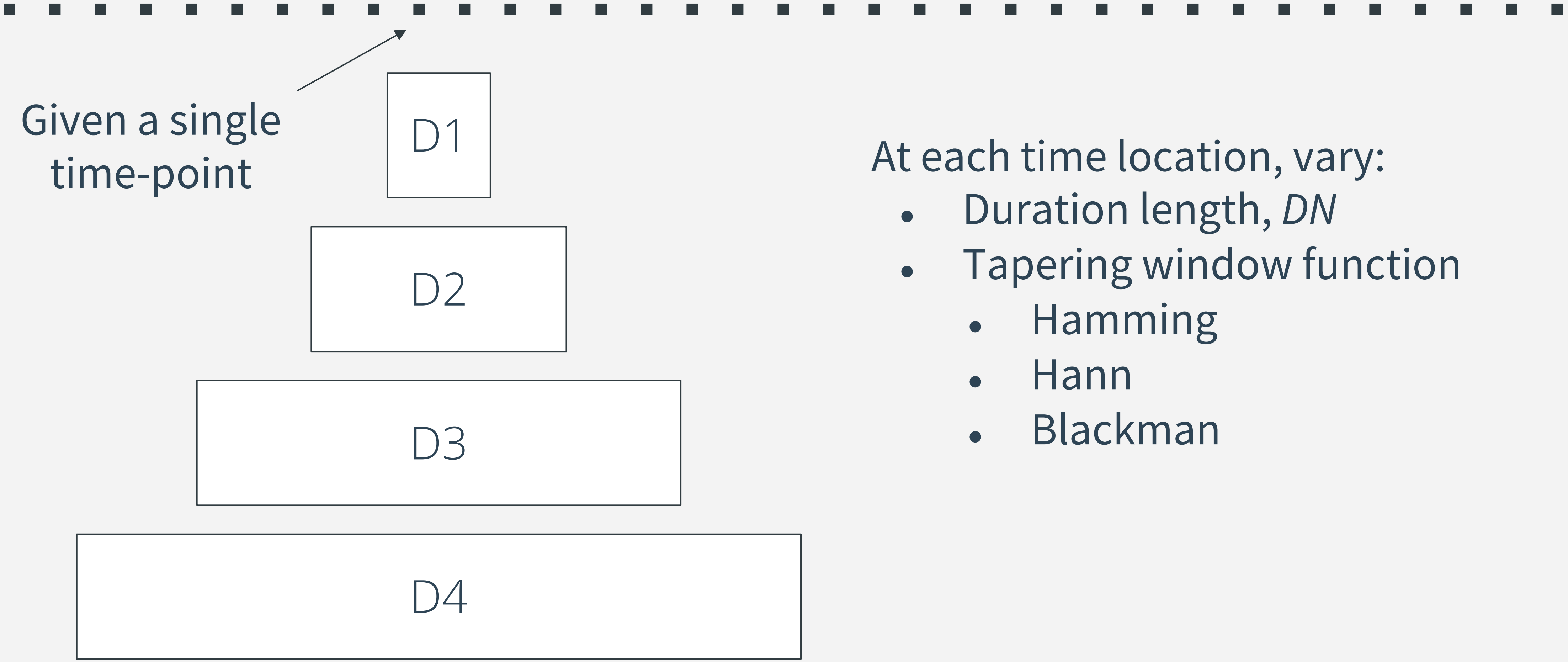
3. Extracts histories from cropped spectrograms

4. Collapses all histories into a single heatmap

5. Extracts final history and 95% confidence interval from the heatmap



How are duration length and overlap ratio coupled?



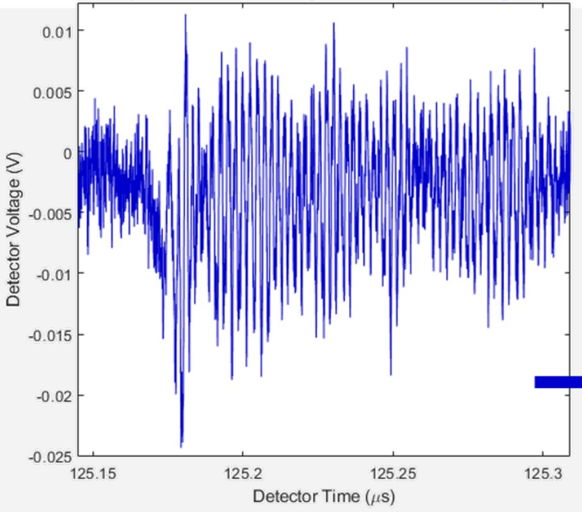
Given a single time-point

At each time location, vary:

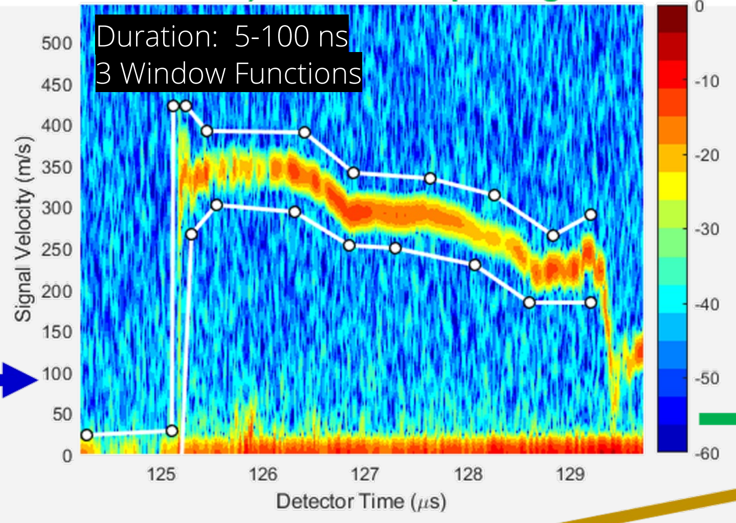
- Duration length, *DN*
- Tapering window function
  - Hamming
  - Hann
  - Blackman

How does the code work?

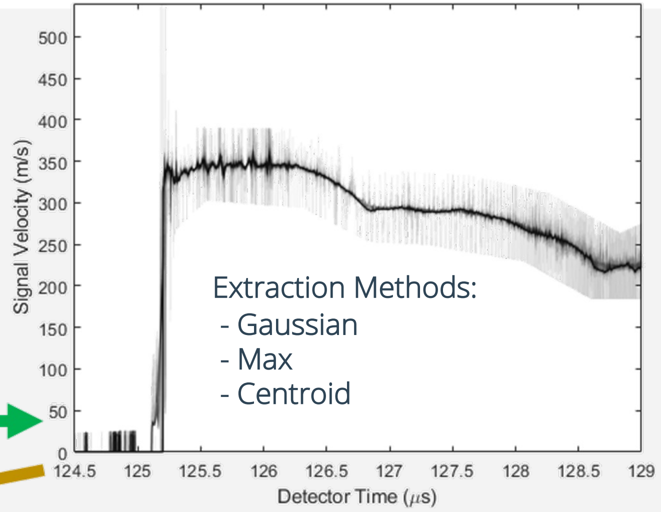
Import and Crop Raw PDV Signal



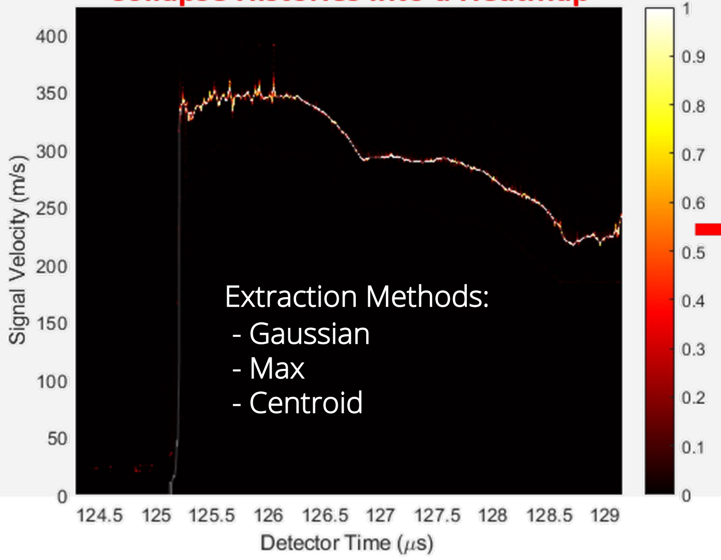
Define ROI, Produce 60 Spectrograms


Duration: 5-100 ns
3 Window Functions

Extract 3 Histories Per Spectrogram


Extraction Methods:
- Gaussian
- Max
- Centroid

Collapse Histories into a Heatmap


Extraction Methods:
- Gaussian
- Max
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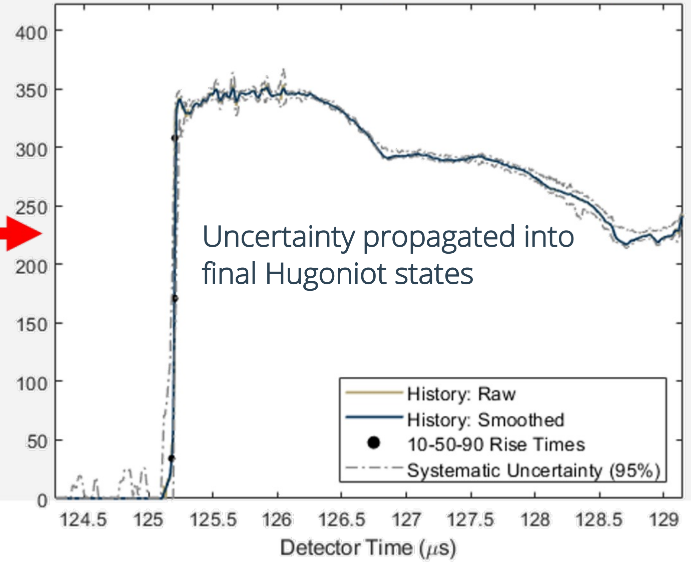
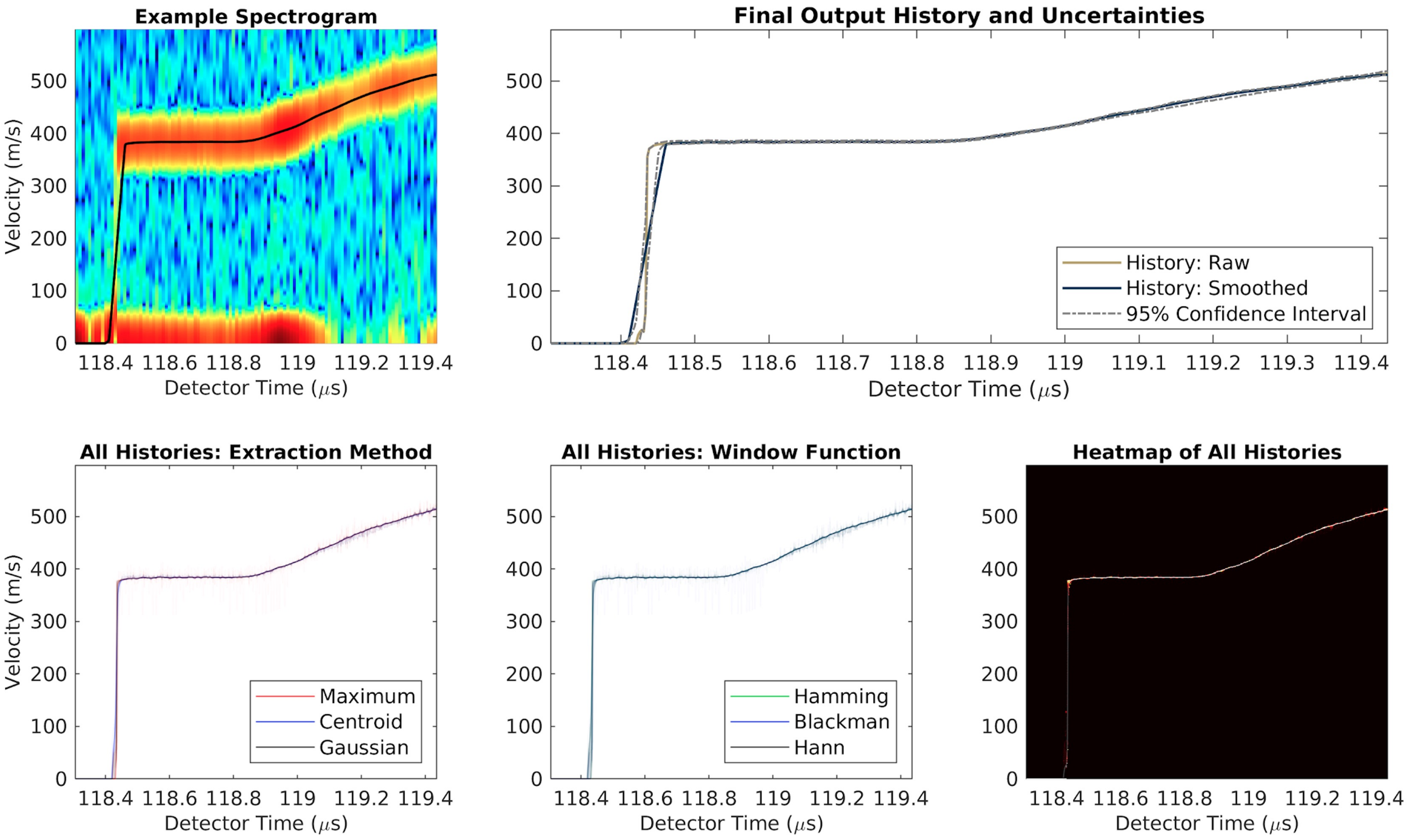
Extract Final History From Heatmap


Uncertainty propagated into final Hugoniot states

Shot1907, Probe 1: Copper-Baseplate



Example Spectrogram

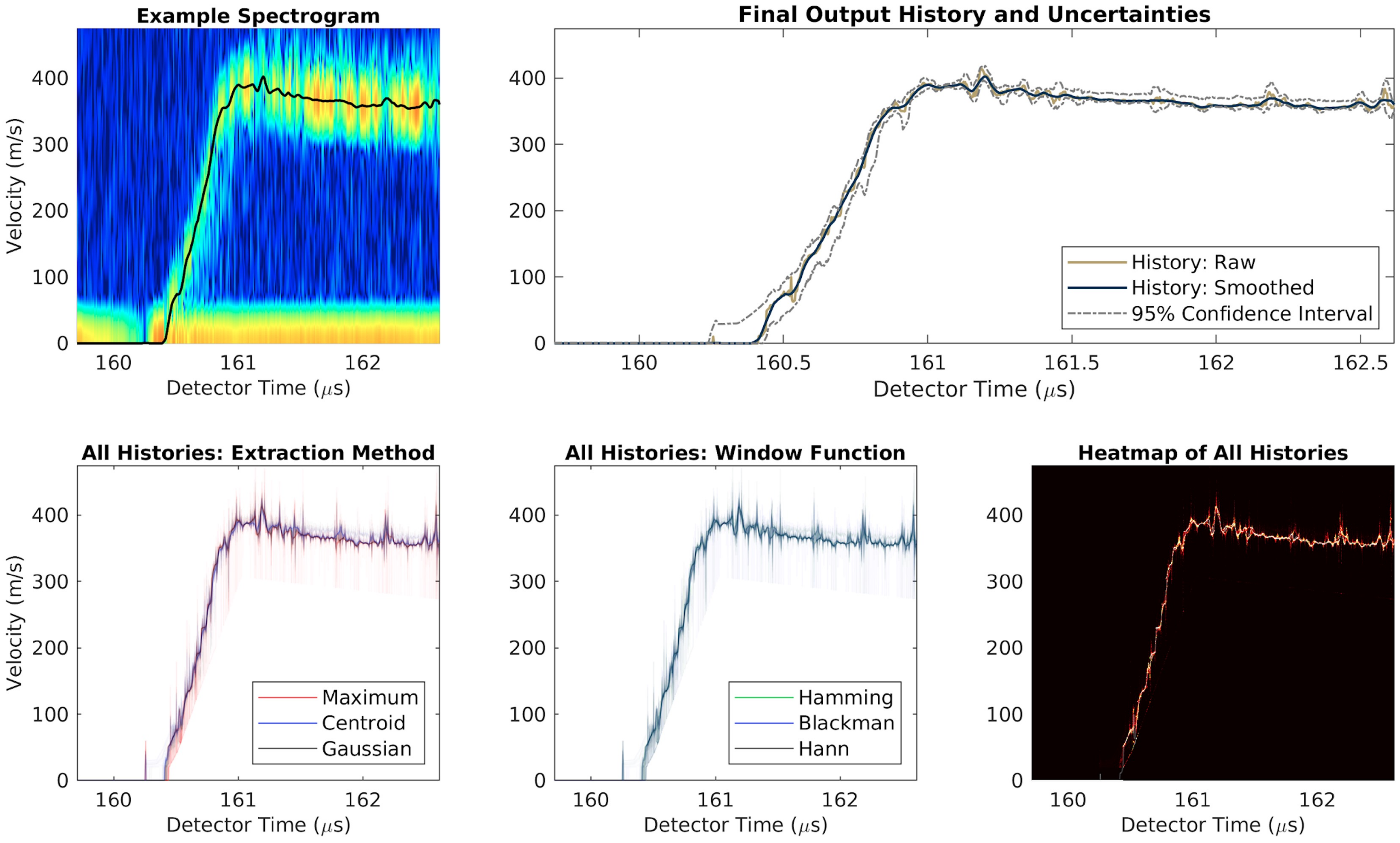
Final Output History and Uncertainties

All Histories: Extraction Method

All Histories: Window Function

Heatmap of All Histories

Shot1930, Probe MockAMEM: Example



Example Spectrogram

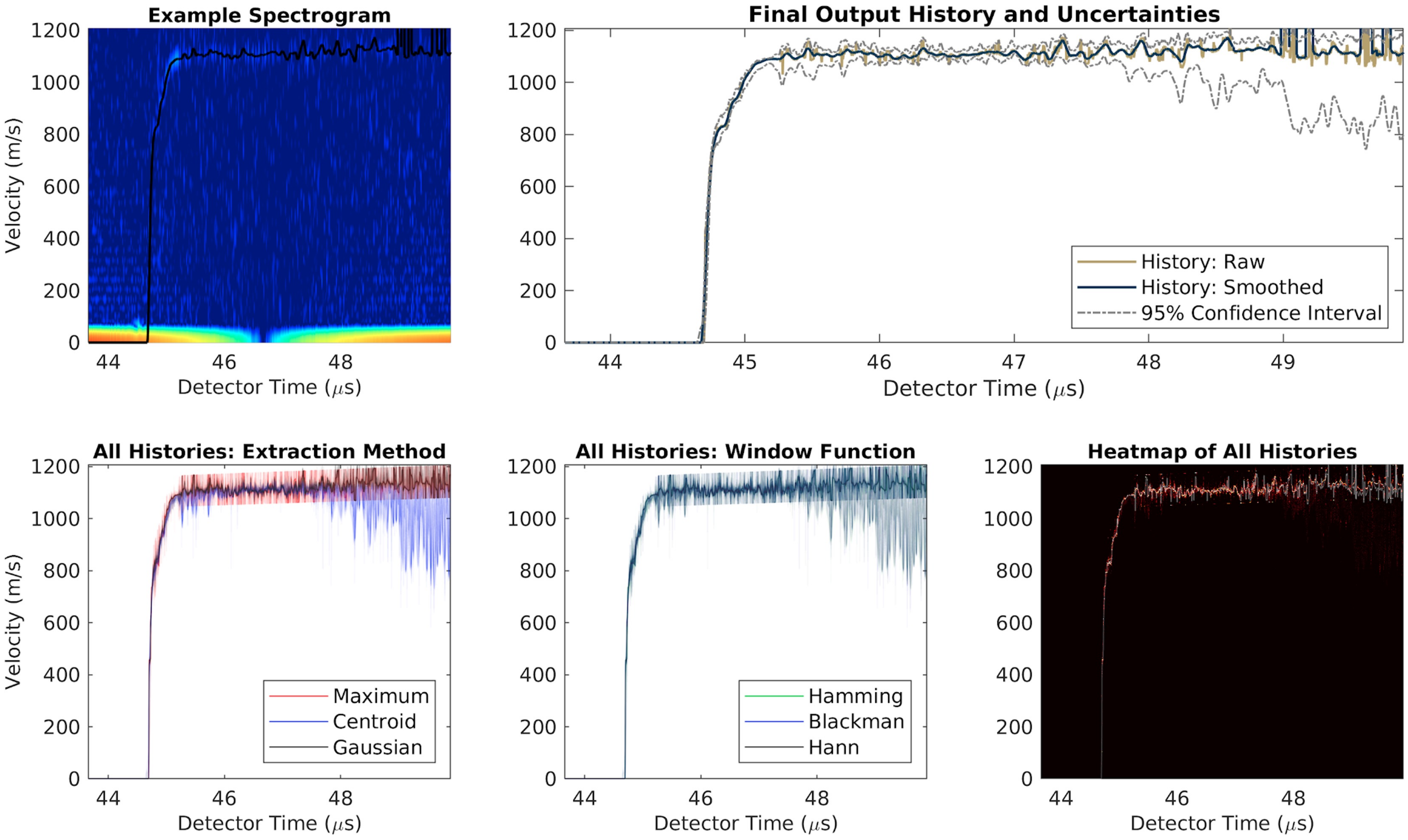
Final Output History and Uncertainties

All Histories: Extraction Method

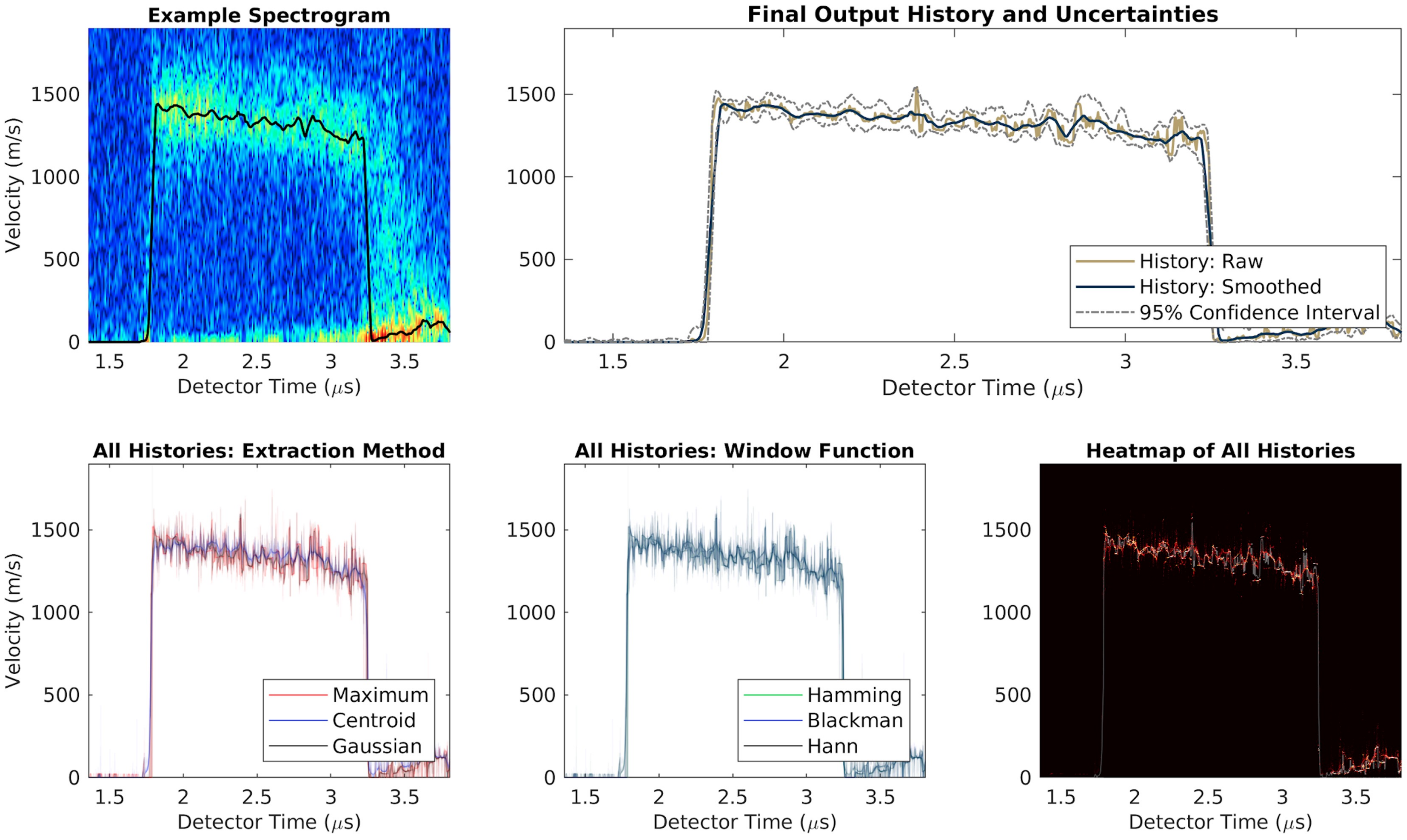
All Histories: Window Function

Heatmap of All Histories

Shot1707, Probe TiB_2-Confinement: Low-SNR-Example



Shot APS-19-1-007, Probe S100C1: Multiple-Velocity-Example


Example Spectrogram
Final Output History and Uncertainties
History: Raw
History: Smoothed
95% Confidence Interval
All Histories: Extraction Method
Maximum
Centroid
Gaussian
All Histories: Window Function
Hamming
Blackman
Hann
Heatmap of All Histories
Velocity (m/s)
Detector Time (μs)