Nortek Vectrino Profiler

What we'll cover…

- History of acoustic Doppler velocimetry
- The Basics of Pulse Coherent Processing
- Profiling considerations and the importance of probe geometry
- Vectrino Profiler Software - configuration, data collection, and export
- Example applications and datasets

- **Acoustic Doppler Velocimetry generically refers to bi-static (separated transmitter and receiver) measurement systems like the Nortek Vectrino and Vectrino Profiler.**

A bit of history…

Lhermitte, R., & Serafin, R. (1984). Pulse-to-pulse coherent Doppler sonar signal processing techniques. *Journal Of Atmospheric And Oceanic Technology, 1*(4).

Stanton, T.P. (1990). Oceanic turbulence measurements using a coherent bi-static acoustic Doppler profiler. 119th Meeting of the Acoustical Society of America.

1996 NortekAS founded. The Nortek NDV offered for sale.

Lhermitte, R., & Lemmin, U. (1994). Open-channel flow and turbulence measurement by high-resolution Doppler sonar. *Journal Of Atmospheric And Oceanic Technology, 11*, 1295–1308.

Snyder, W., & Castro, I. (1999). Acoustic Doppler velocimeter evaluation in stratified towing tank. *Journal Of Hydraulic Eng., 125*(6), 595–603.

1999 Nortek Vector introduced

Kraus, N.C.,& Lohrmann, A, & Cabrera, R. (1994). New Acoustic Meter for Measuring 3D Laboratory Flows. *J. Hydraulic Eng.* 120, 406.

Lohrmann, A., Cabrera, R. and Kraus, N.C. (1994). Acoustic-Doppler Velocimeter (ADV) for Laboratory Use. Fundamentals and Advancements in Hydraulic Measurements and Experimentation.

2005 Nortek Vectrino introduced

2008 Nortek Scientific founded

2011 Nortek Vectrino Profiler introduced

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The Original ADV

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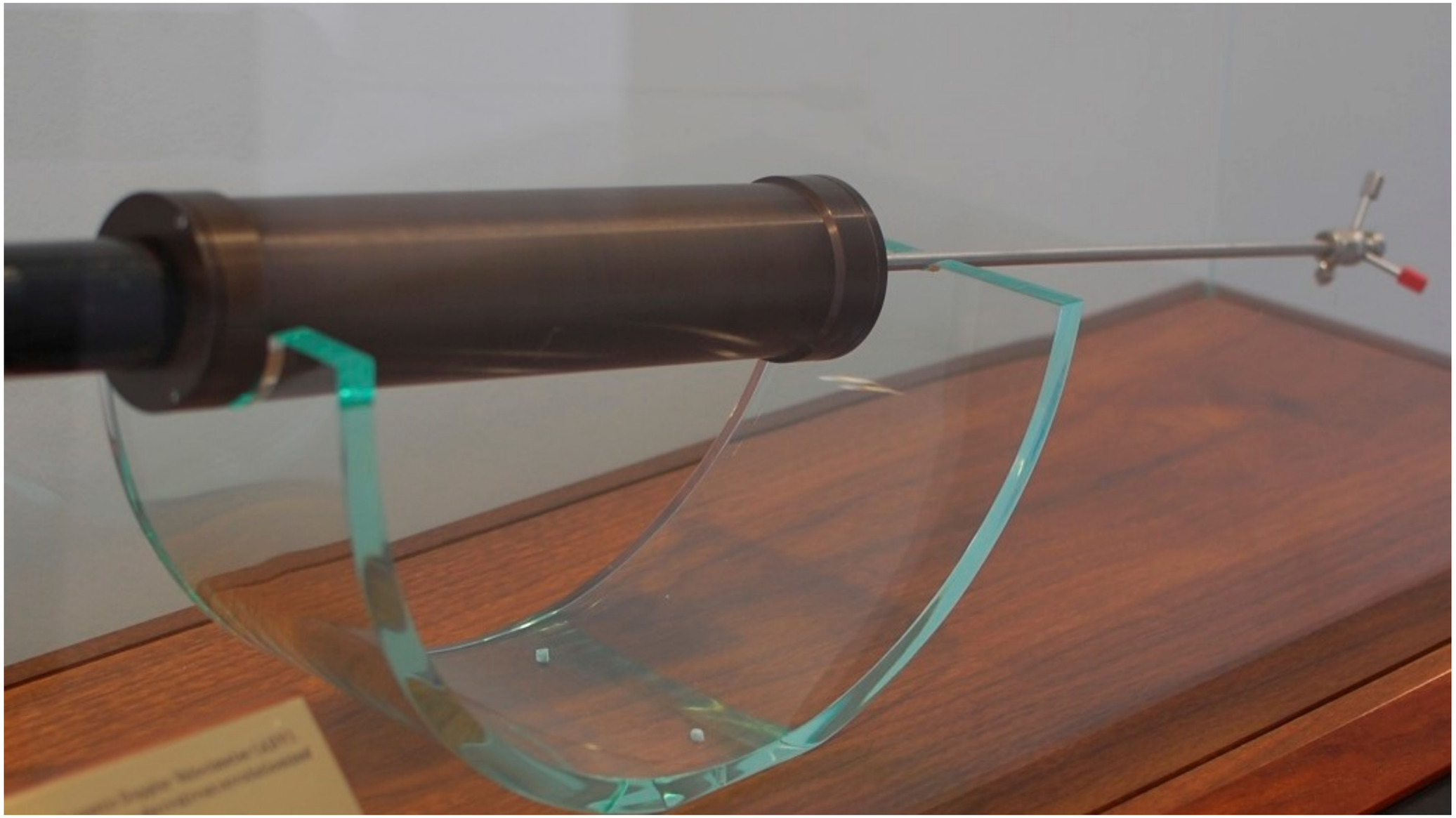

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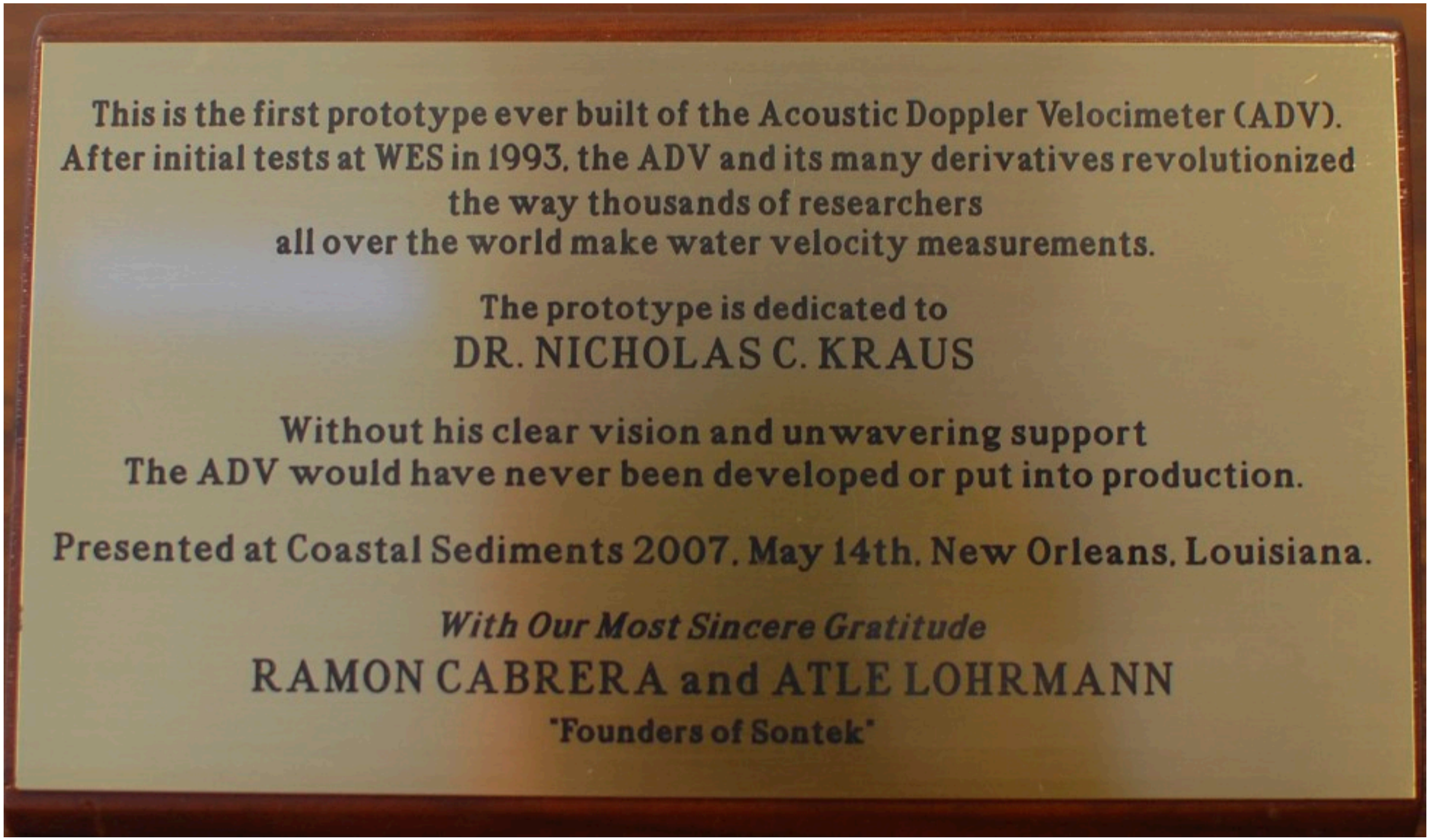

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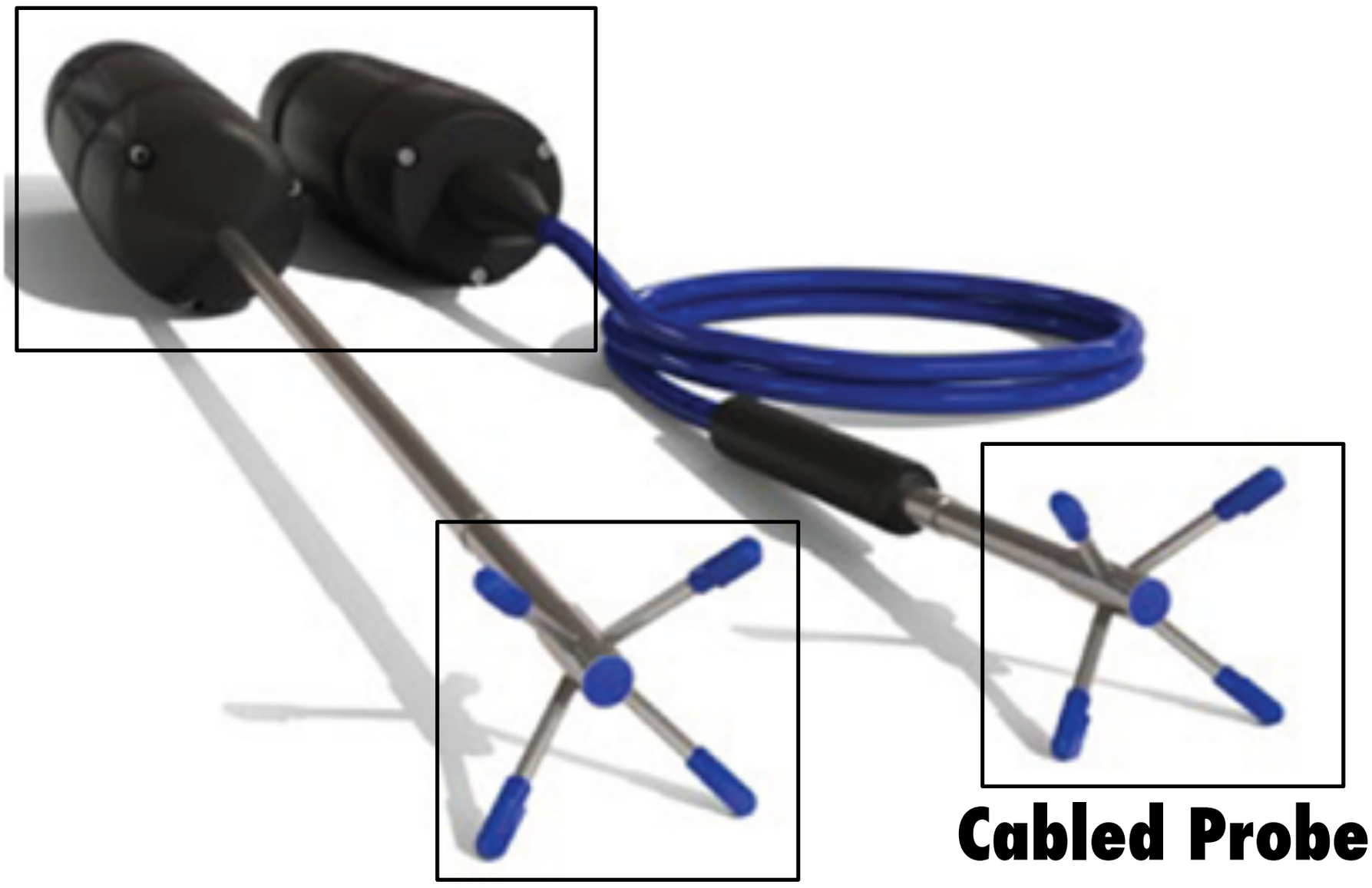
Acoustic Doppler velocimeters have a 20 year history in research and engineering applications.

We are now 4-5 generations of students past their initial introduction to the scientific community.

Doppler velocimeters and pulse coherent processing are complex instruments. Understanding basic functions will lead to better data quality and more robust operation.

Electronics Housing



Fixed Probe

Cabled Probe

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Electronics

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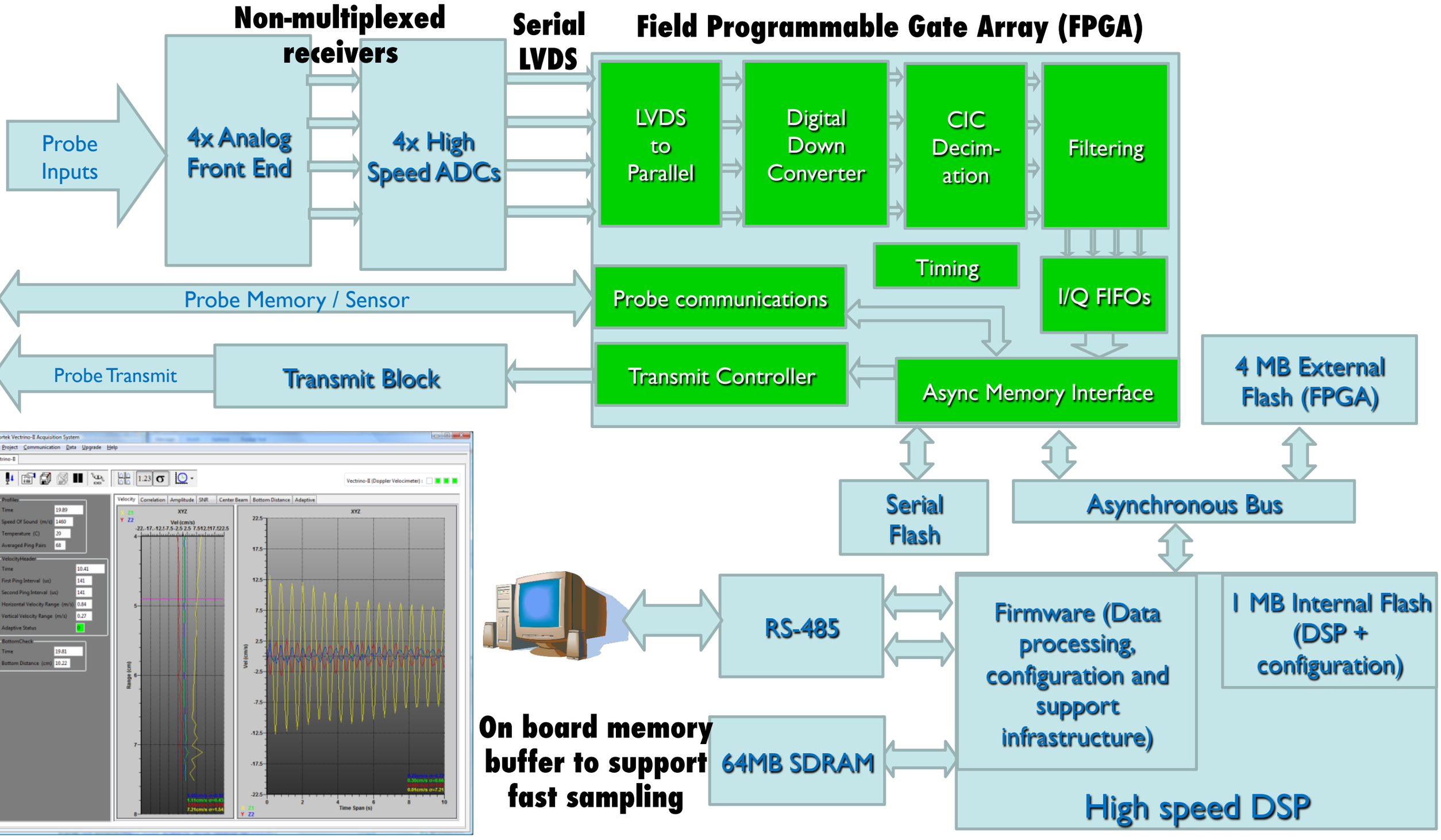

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Probe Head

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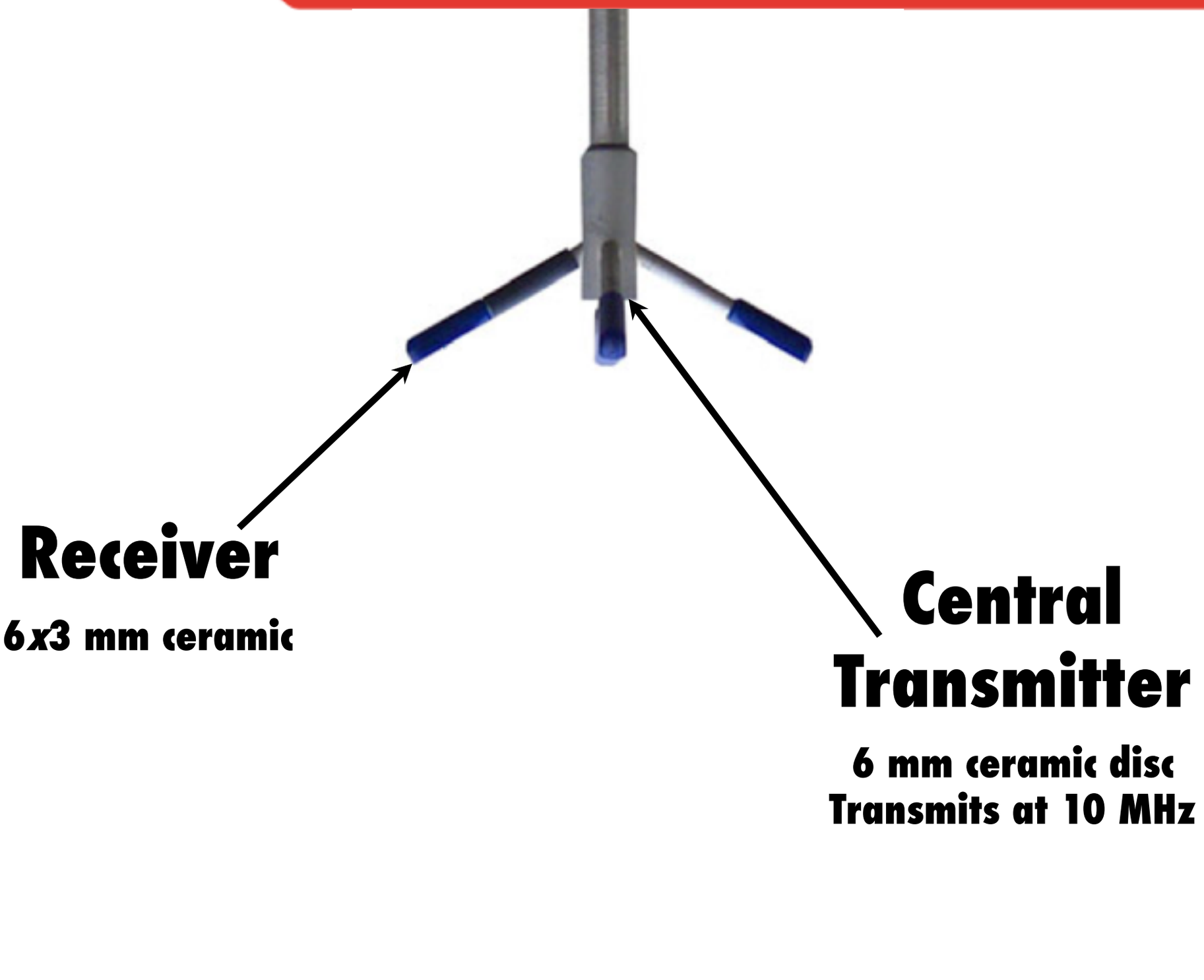

Receiver

6x3 mm ceramic

Central Transmitter

6 mm ceramic disc
Transmits at 10 MHz

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Probe Head End View

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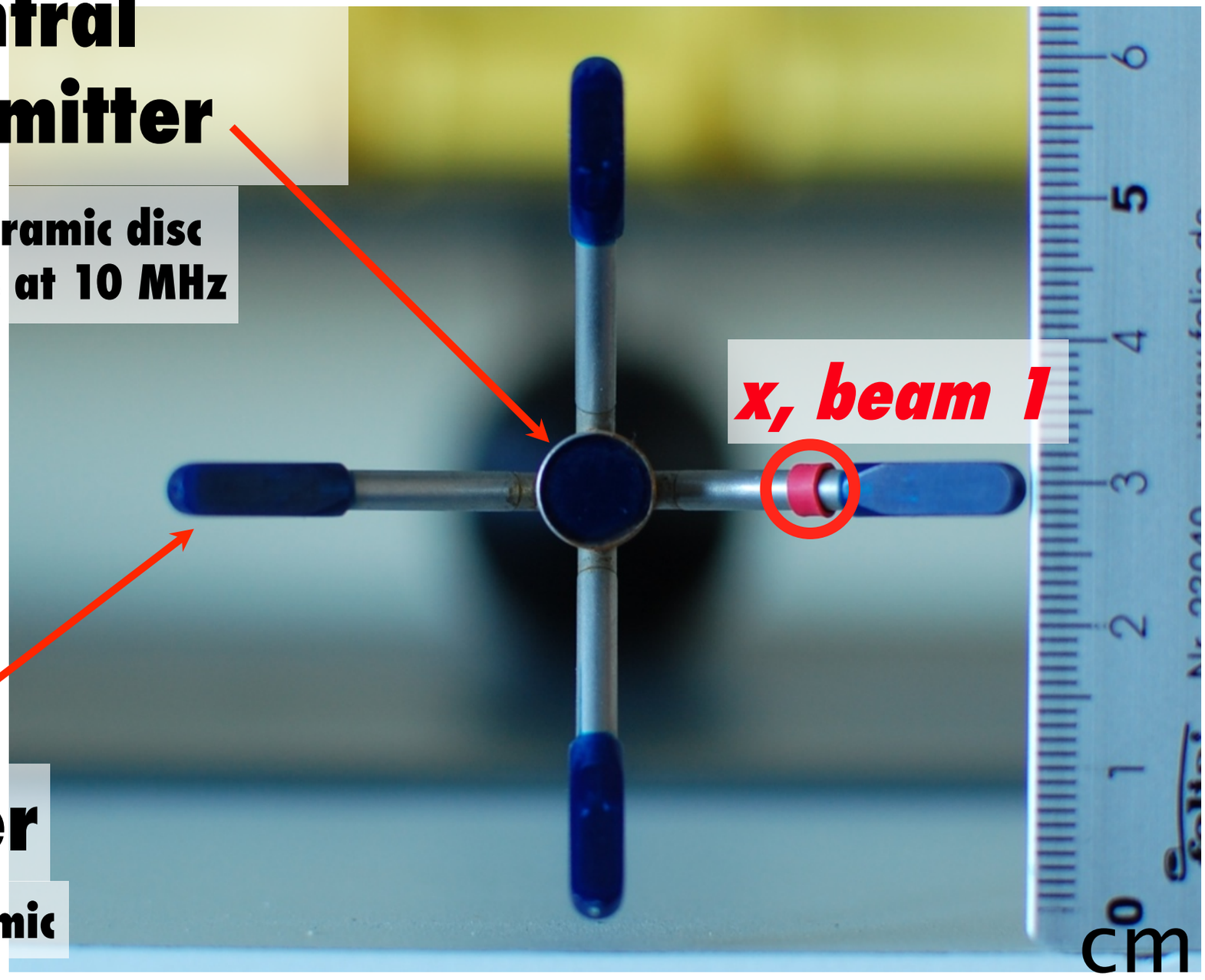


Pulse Coherent Processing

- **The Doppler shift (Δf) is estimated from a change in phase ($\Delta\phi$)between two signals.**
- **Basic operation is ping-listen-ping-listen. There is expected to be one pulse in the water at any time in the sample volume.**
- **This method produces high spatial resolution, low noise data.**
- **There are tradeoffs between maximum velocity, profile range and sample rate.**

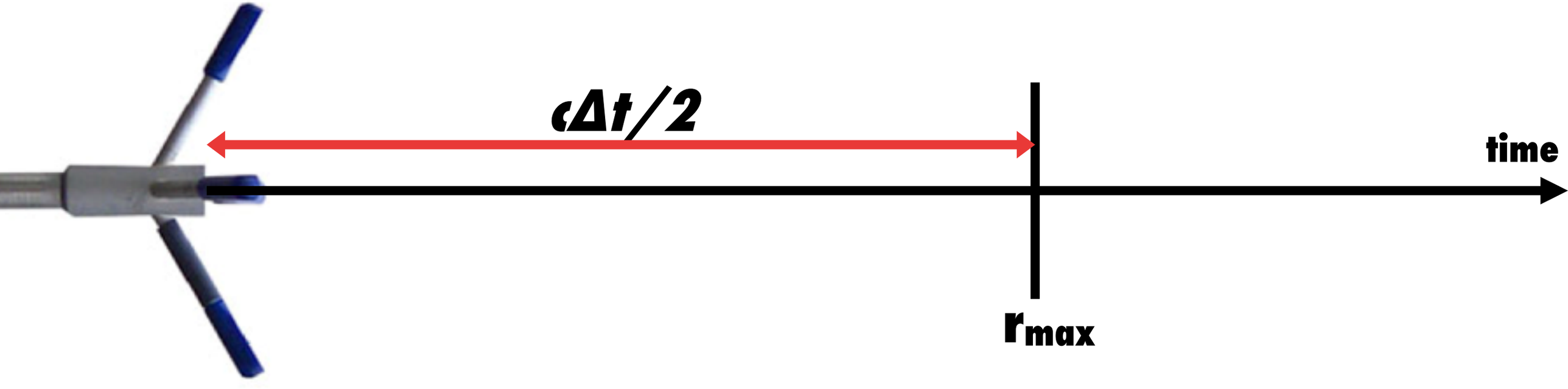
Lhermitte, R., & Serafin, R. (1984). Pulse-to-pulse coherent Doppler sonar signal processing techniques. Journal Of Atmospheric And Oceanic Technology, 1(4), 293-208.

Ambiguity Range

- **There is an unambiguous range, r_{max}, for pulse coherent operation.**

$$r_{max} = \frac{c}{2f_{pr}}$$

$$r_{max} = \frac{c\Delta t}{2}$$

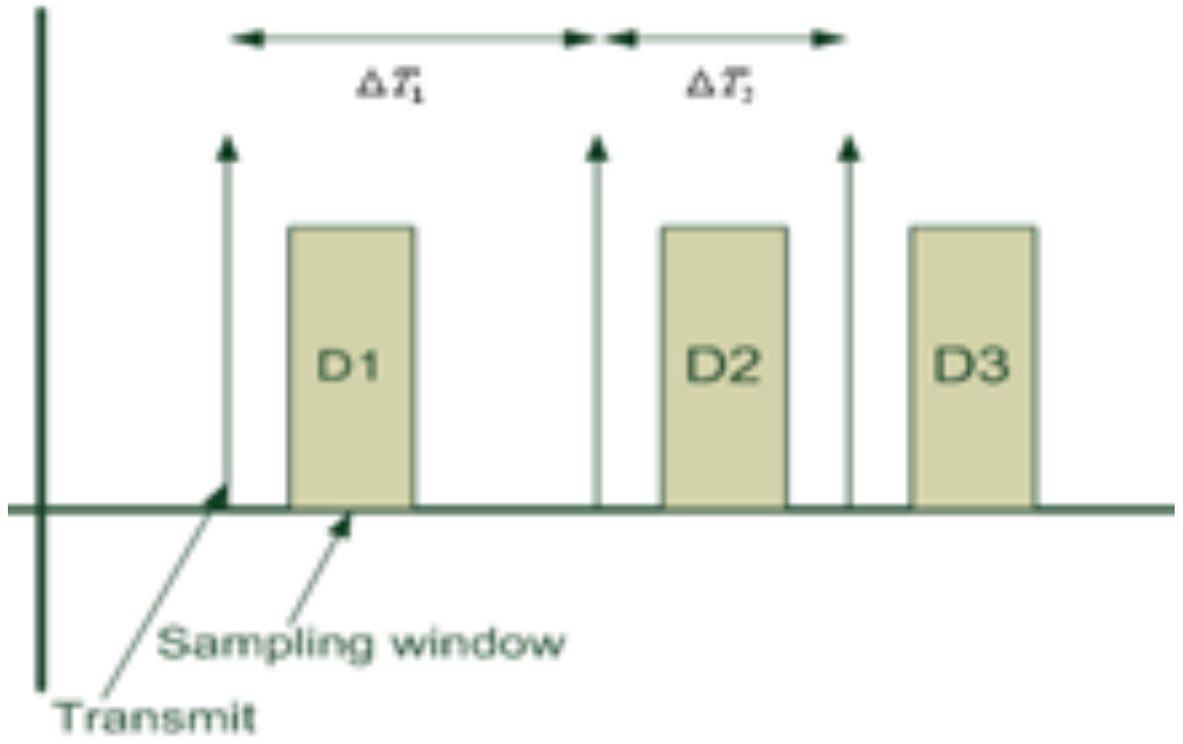


User Ambiguity Control

- The user has control of PRT through the Velocity Range parameter.
- This basic pulse coherent scheme permits maximum horizontal velocities of about 1.3 m/s to be measured.
- What about sampling higher velocities?

Dual PRF Mode

- **Two Pulse Repetition Times are used to extend the ambiguity velocity.**
- **This is a direct measure of velocity, there is no inferred phase wrapping.**
- **Limited to a gain of 3-4 times the single PRF ambiguity velocity.**



$$V_{max} = \frac{c}{4f(\Delta t_1 - \Delta t_2)}$$

$$= \frac{c}{4f\Delta t_1} \frac{\Delta t_1}{\Delta t_1 - \Delta t_2}$$

$$\Delta t_1 > \Delta t_2$$

Srivastava, R., Jameson, A., & Hildebrand, P. (1979). Time-domain computation of mean and variance of Doppler spectra. Journal of Applied Meteorology, 18, 189–194.
Zedel, L., & Hay, A. E. (n.d.). Resolving Velocity Ambiguity in Multifrequency, Pulse-to-Pulse Coherent Doppler Sonar. IEEE Journal of Oceanic Engineering, 35(4), 847–851.

Dual PRF Mode

- **For the Vectrino Profiler, this extends the maximum horizontal velocity to 3.0 m/s.**
- **Roughly halves the number of internal samples, resulting in a larger variance.**
- **Requires better signal quality in order to produce reasonable velocity estimates, because there is less ensemble averaging at a given sample rate and the estimate of $\Delta\phi$ using Dual PRF is inherently noisier.**

Profiling Considerations and Probe Geometry

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Sample Volume of a Single Point Sensor

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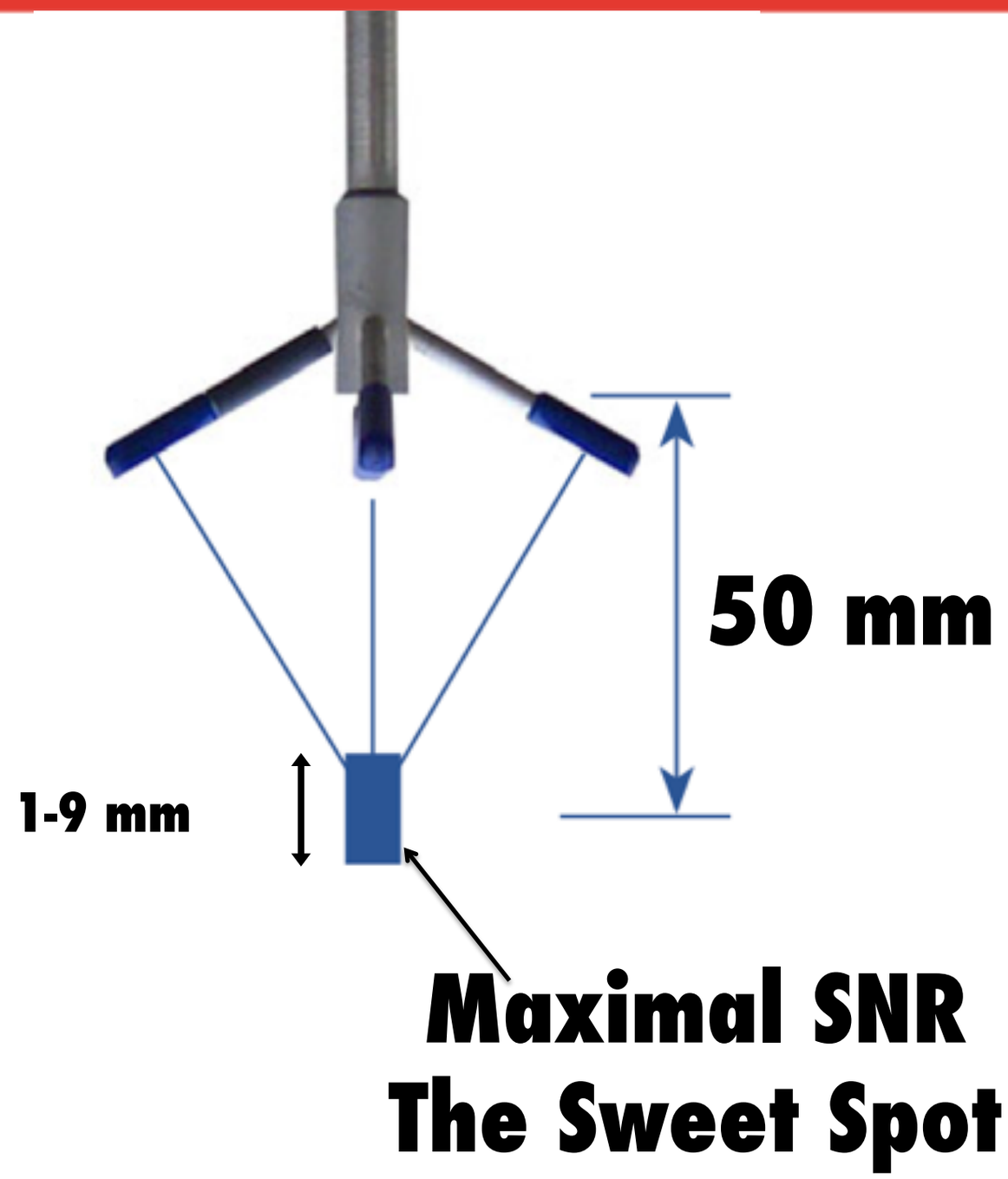
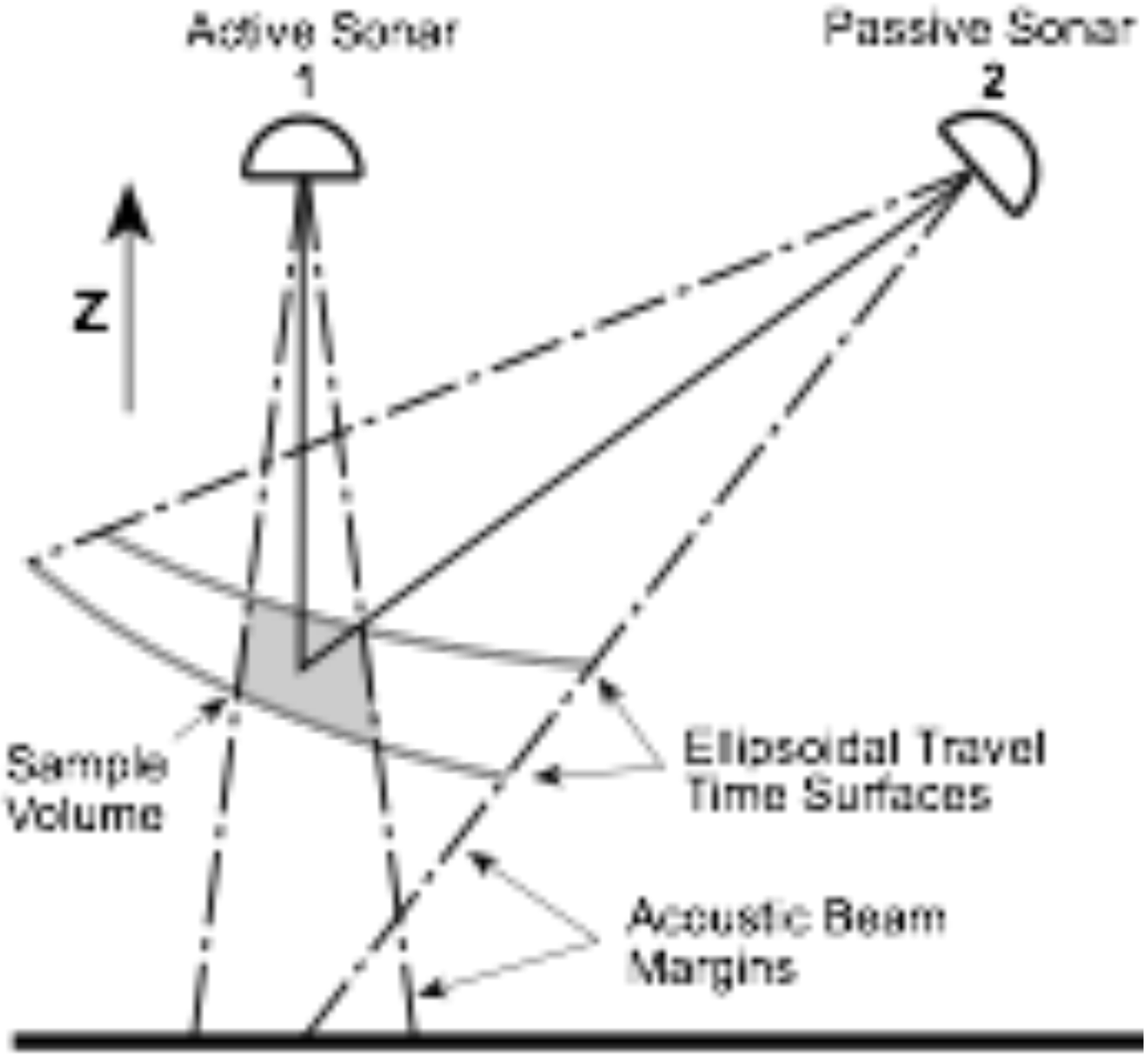


Sample Volume Shape



- The intersecting beam patterns define two of the sample volume dimensions.
- Range gating defines the third dimension.

Zedel, L. (2002). A three-component bistatic coherent Doppler velocity profiler: error sensitivity and system accuracy. Oceanic Engineering.

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A Range Gated Profile

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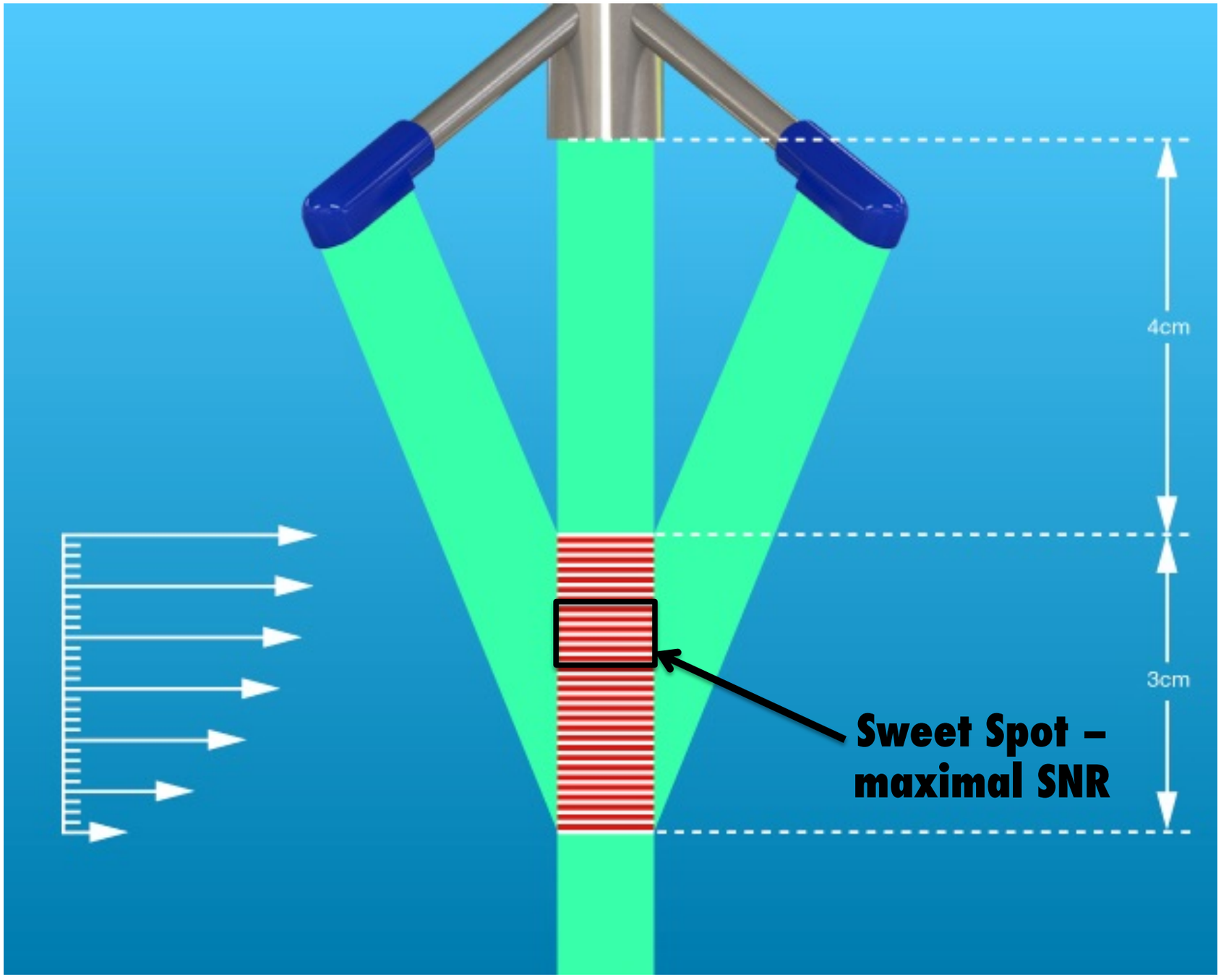

Noise, Amplitude, and SNR Profiles

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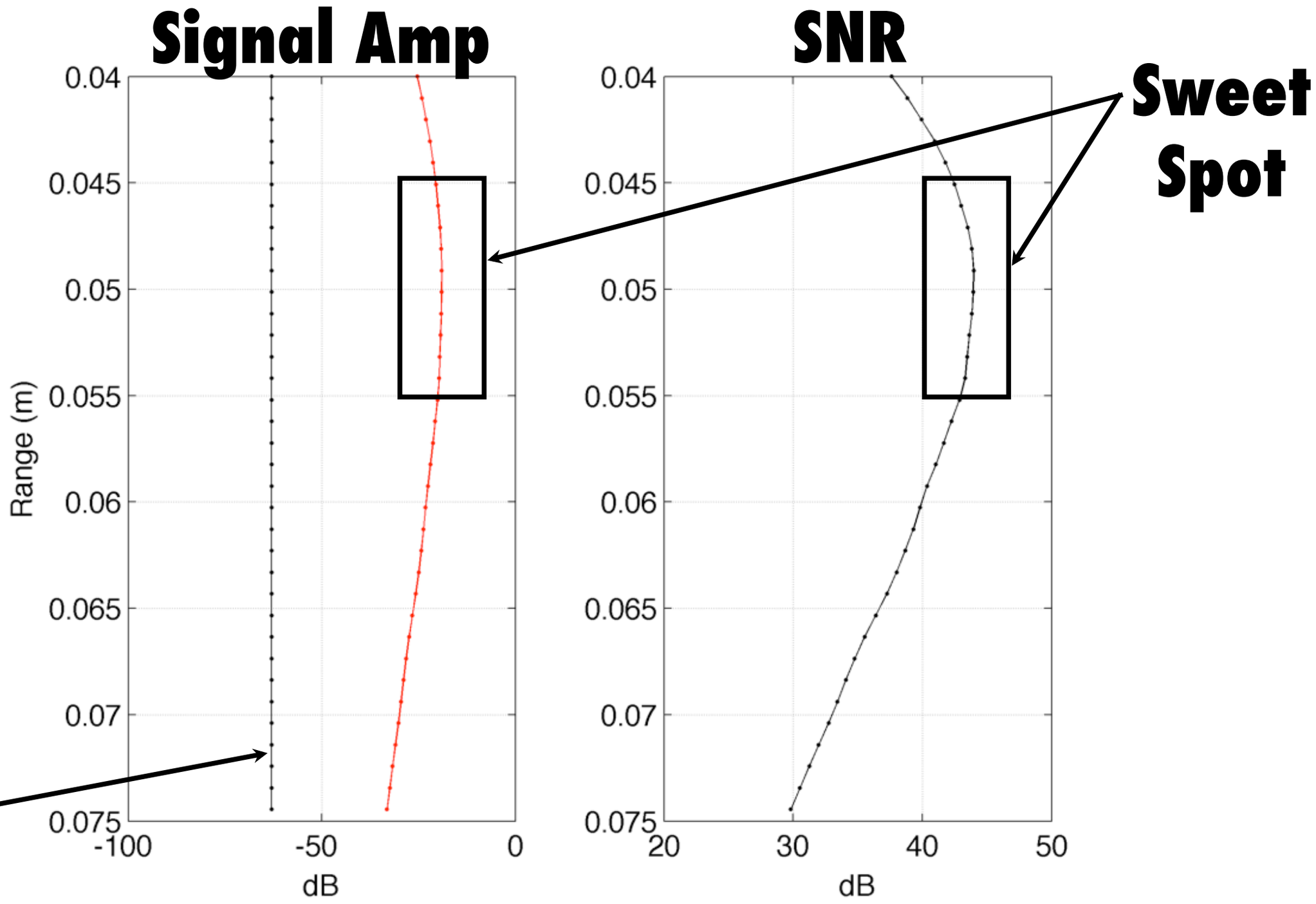
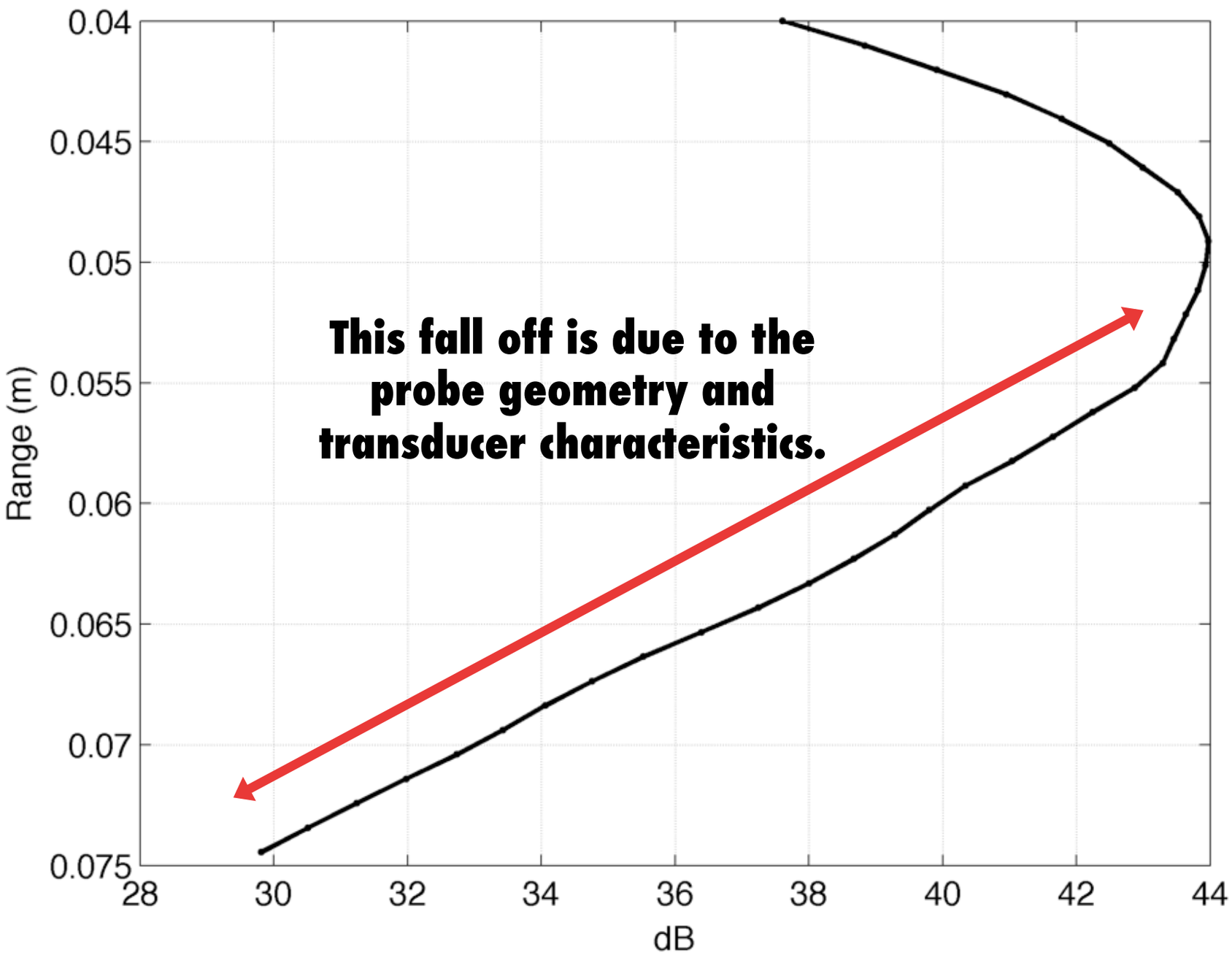
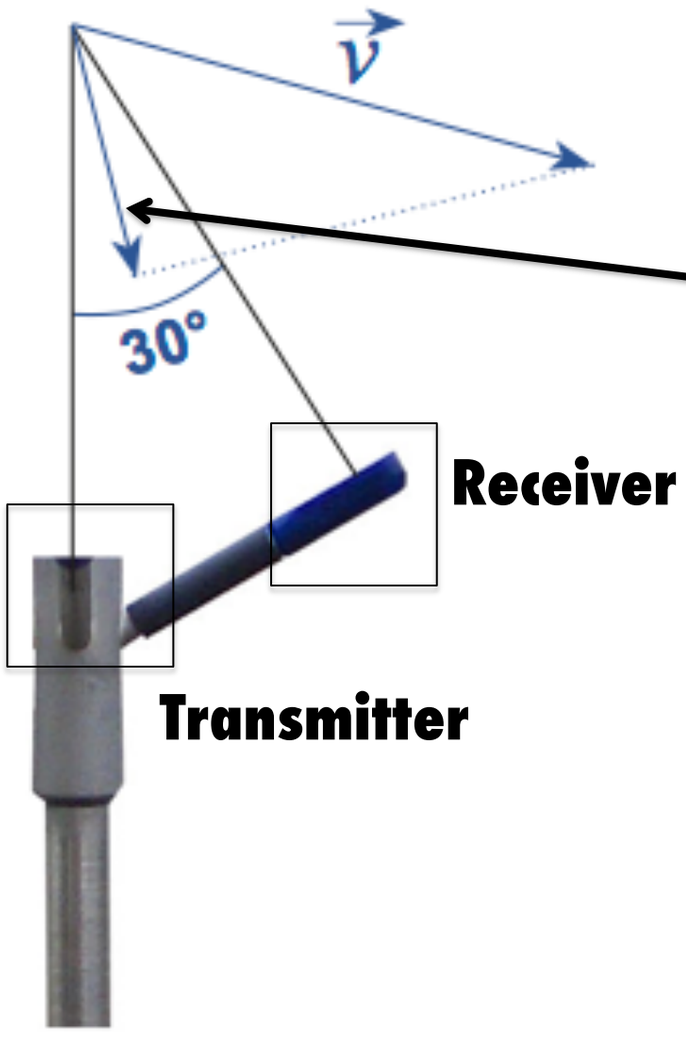


SNR Profile


This fall off is due to the probe geometry and transducer characteristics.
Range (m)
0.04
0.045
0.05
0.055
0.06
0.065
0.07
0.075
28
30
32
34
36
38
40
42
44
dB

Velocity Measurement



- **The transmitter and receiver are separated physically (bi-static).**
- **The actual velocity measured is *along the angle bisector* between transmitter and receiver.**
- **The probe geometry has consequences for measurement uncertainty and noise.**

Consequences of Probe Geometry

- There is a strong fall off in signal strength and quality once r > 65 mm.
- This limits the profile range to 75 mm if signal quality is extremely good.
- It also has consequences for velocity measurements and the role of noise variance in the profile.

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The Vectrino Profiler

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True innovation makes a difference

- First commercial bi-static profiler.
- Advanced feature set compared to traditional single point systems.
- Real time profile and time series plots, color contour images, velocity spectra and histograms in acquisition software.
- Data export directly to Matlab.

Vectrino Profiler Specifications

- 1 mm range cells over a 35mm profile.
- 100 Hz maximum data output rate.
- Interleaved bottom distance measurements at up to 10 Hz.
- Multiple ping algorithms available for user Velocity Range control.

Vectrino Profiler - Configuration

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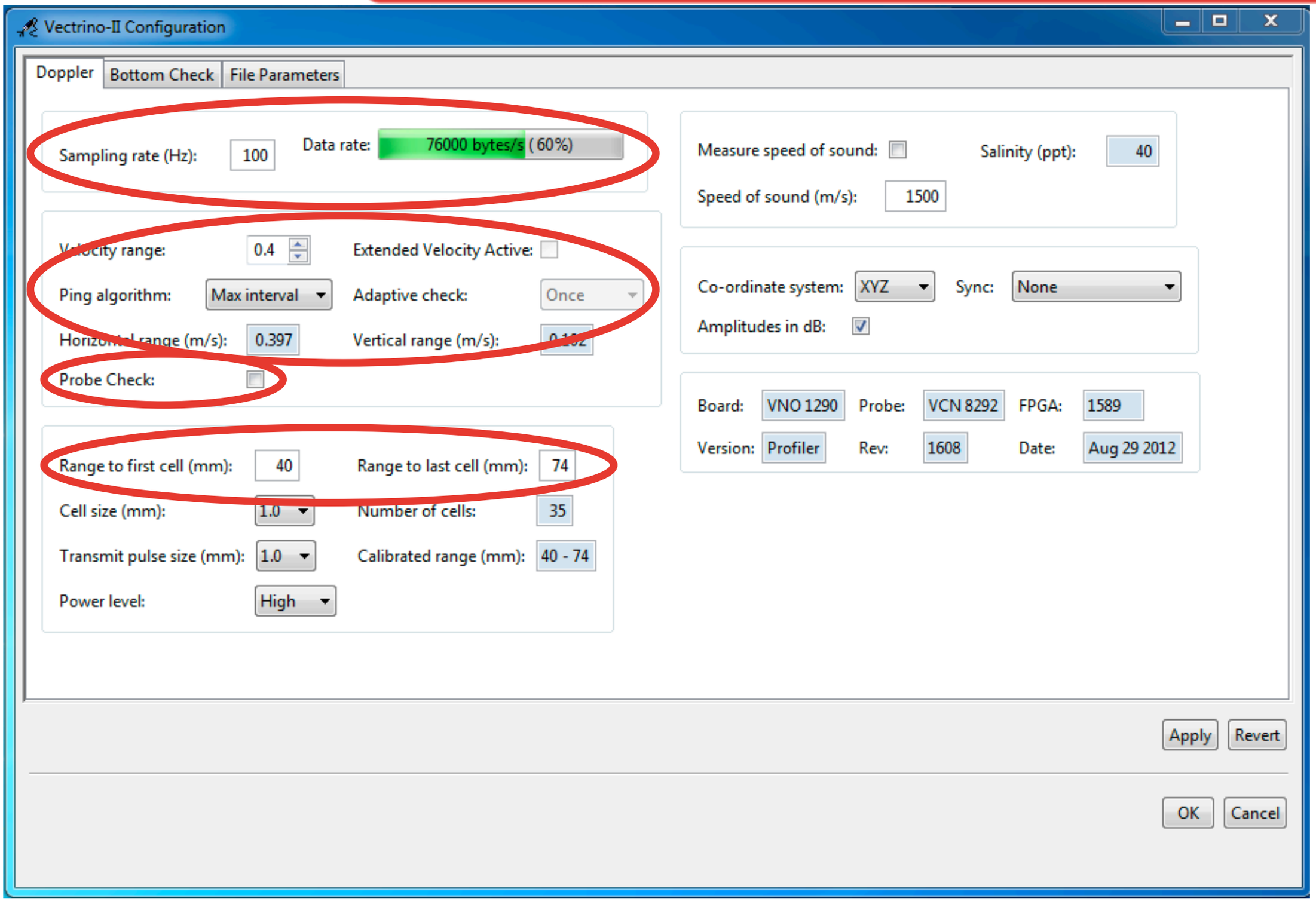
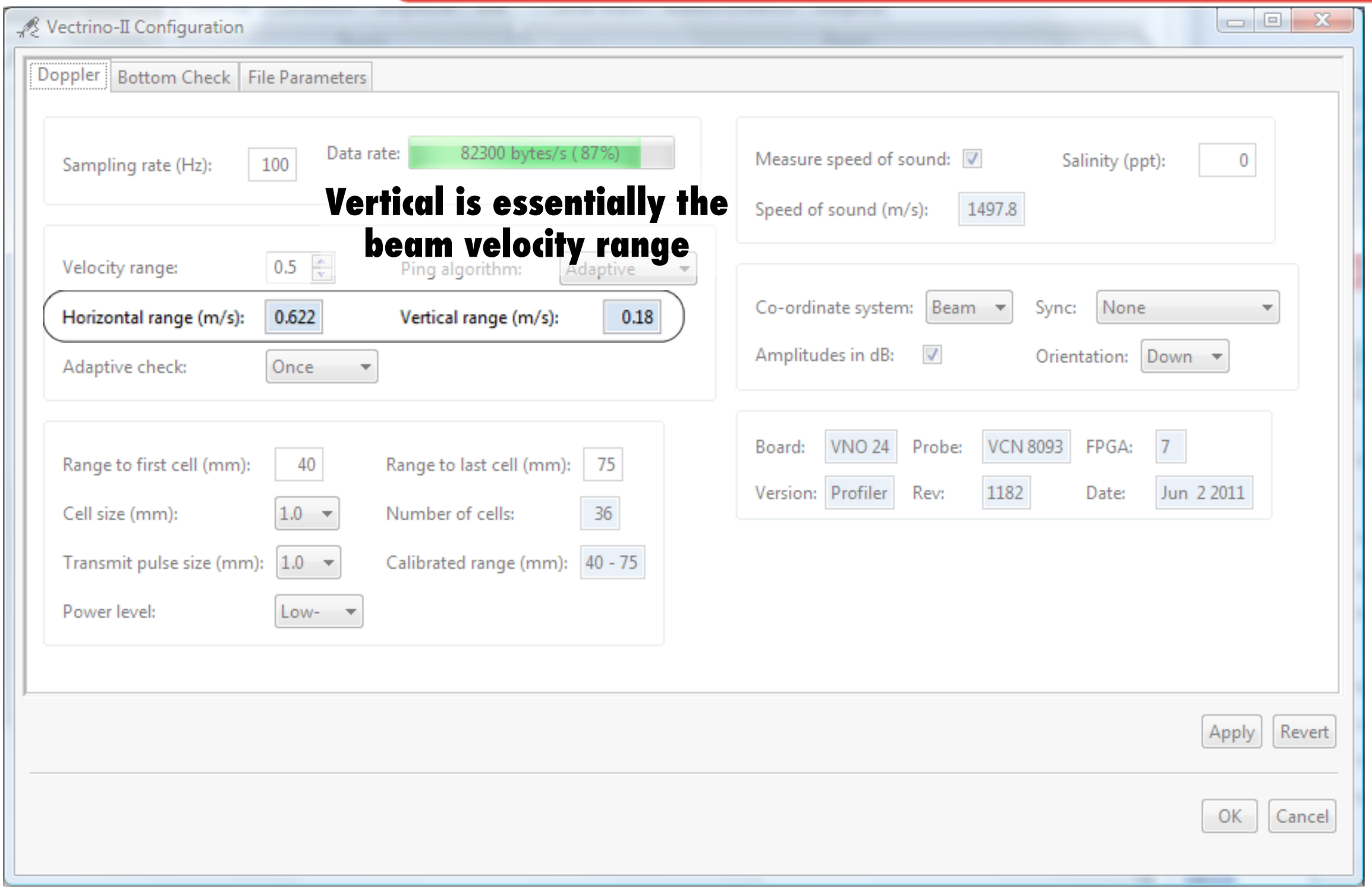


- **Setting the Velocity Range appropriately is the most important step to achieving good data quality.**

Reported Velocity Range



Ping Algorithms

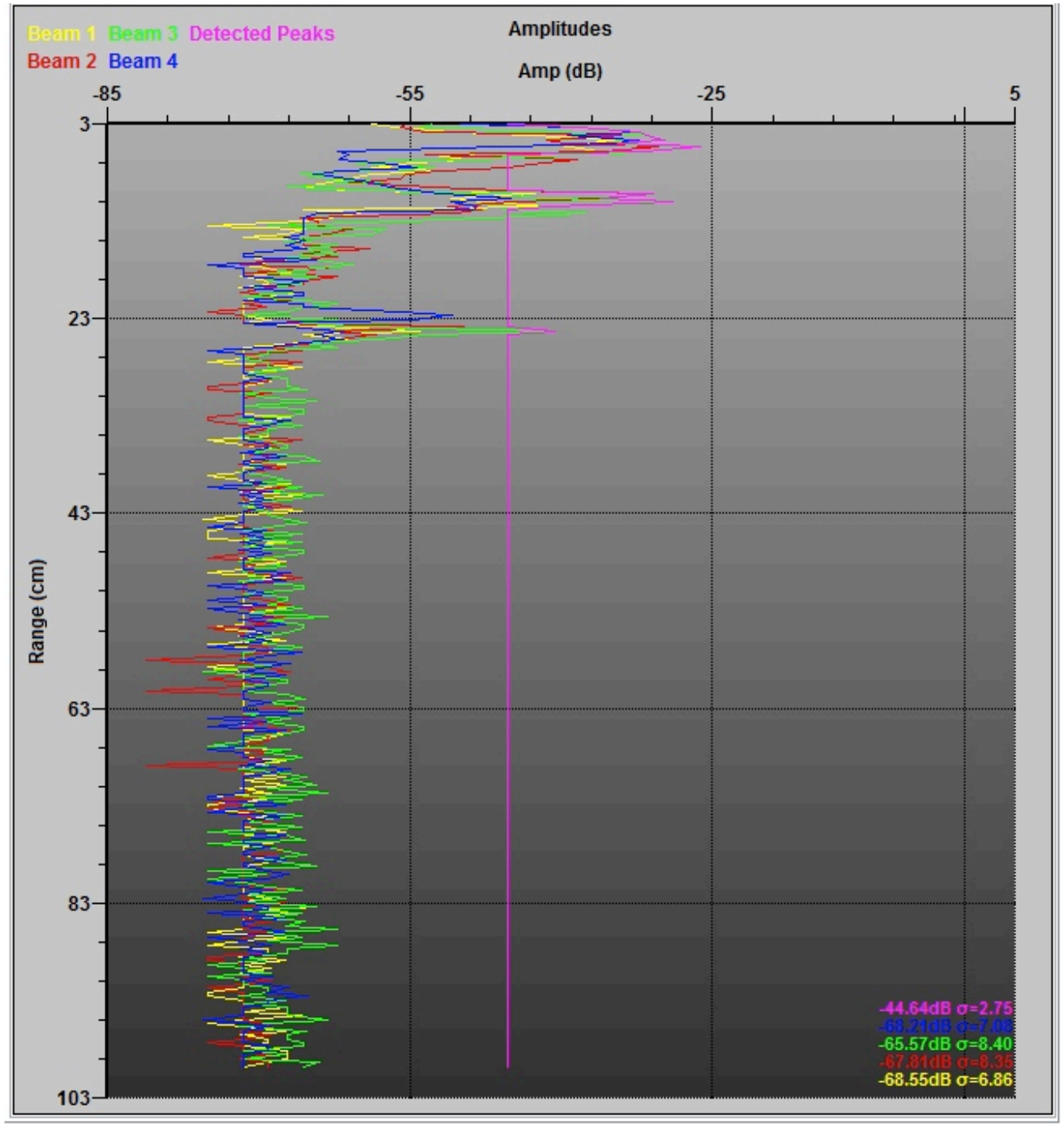
- **Maximum Interval**
  - **Matches ping interval to requested ambiguity velocity.**
  - **This is how single point systems currently work.**
- **Minimum Interval**
  - **Smallest interval that meets velocity and range settings.**
  - **Faster internal sample rate.**
  - **Ambiguity velocity remains constant until 1.4 m/s, then Dual PRF is activated with a constant velocity range until 2.7 m/s when it switches again.**
- **Adaptive**
  - **Automatically adjusts ping intervals to reduce acoustic interference while meeting the user specified Velocity Range.**

Acoustic Interference

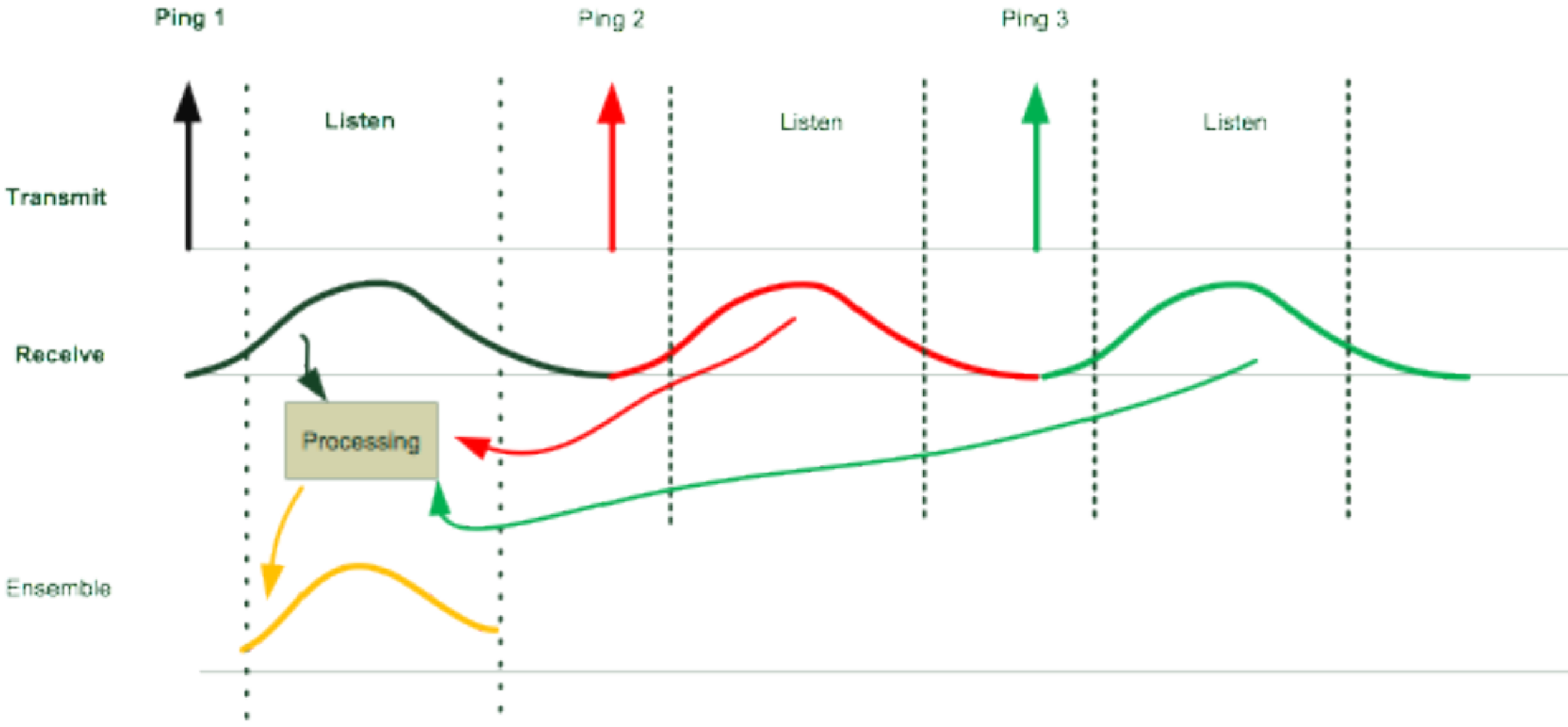
- **Echoes from past pings can affect the present measurements.**

- **Also referred to as pulse interference or weak spots.**

- **The potential for this to occur is significantly increased with a profiler and Dual PRF.**



No Interference



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Acoustic Interference

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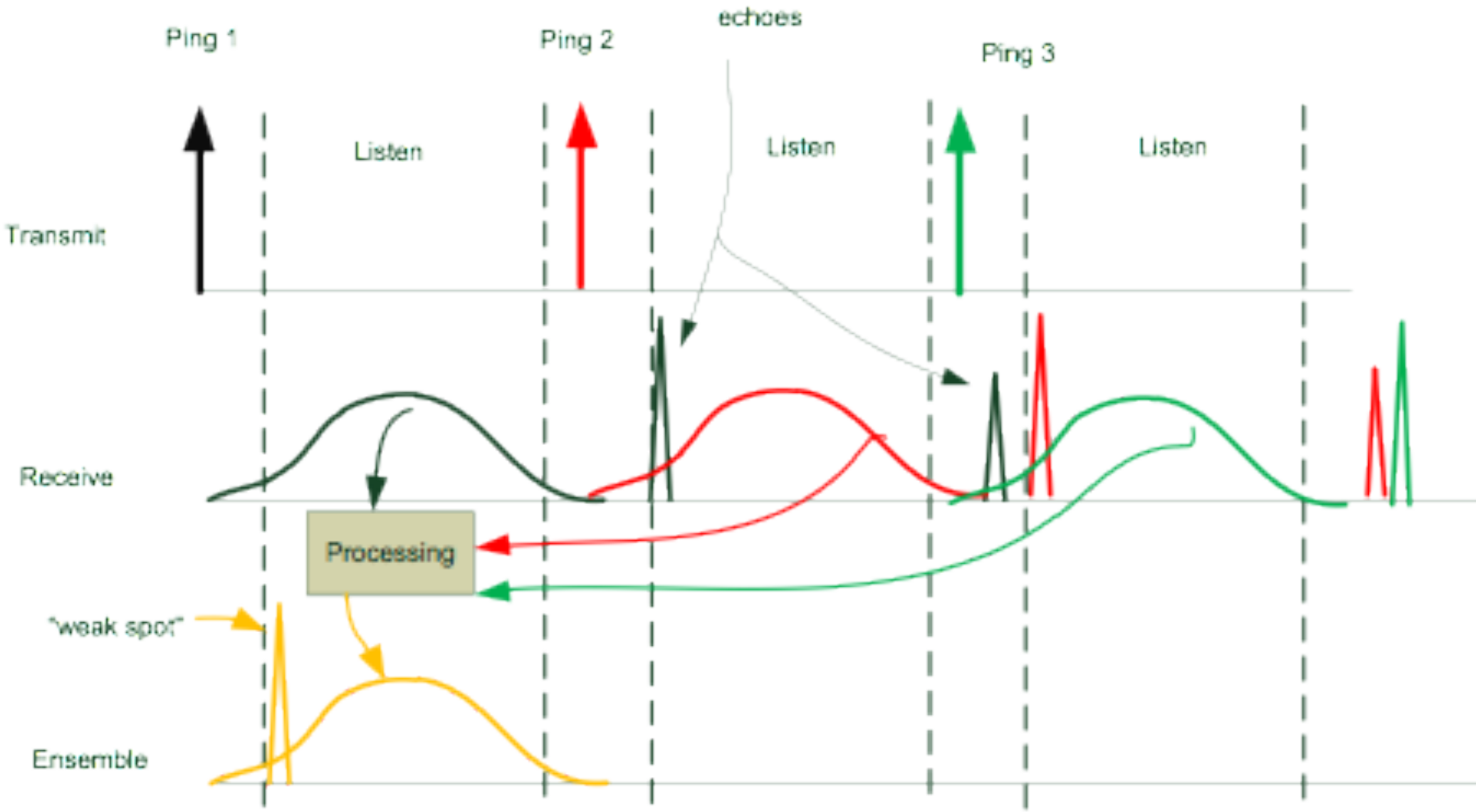
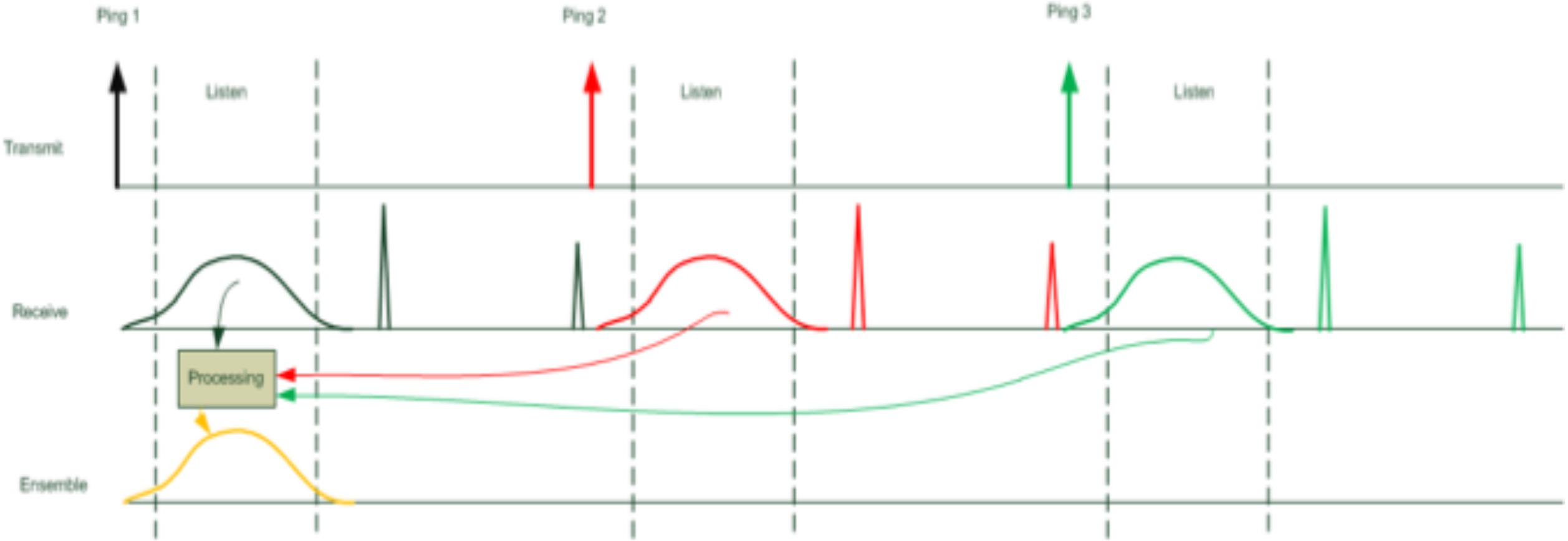


One Solution

- **Increase the pulse distance so it is longer than the boundary distance.**

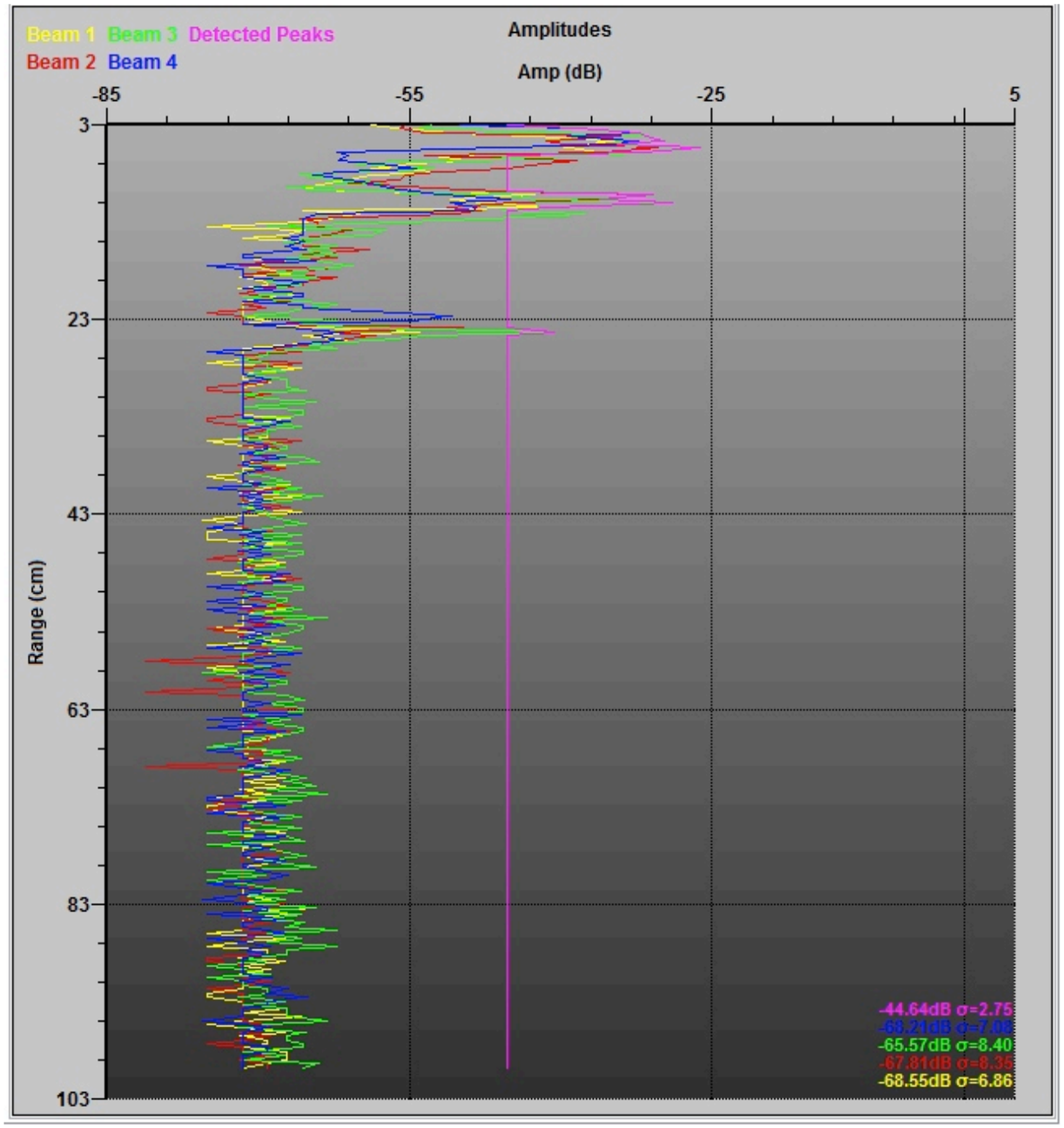


Of course, this has a direct effect on the Velocity Range, decreasing V_{max}.

Adaptive Ping Algorithm

- **The Vectrino Profiler listens to the return echoes and identifies interference regions by their higher amplitude return.**

- **It adjusts the ping intervals to eliminate the interference regions or moves them to the ends of the profile, maintaining at minimum the user specified Velocity Range and profile length.**

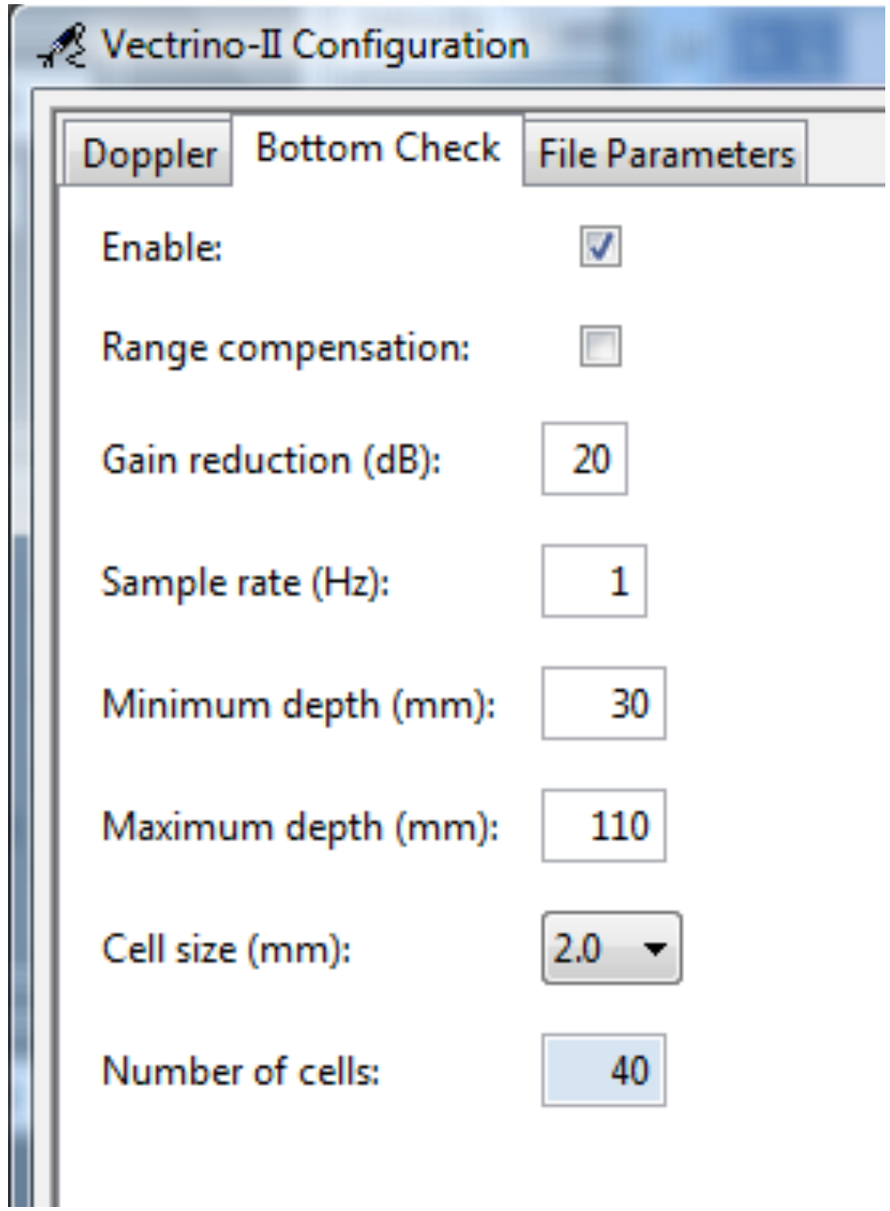


Adaptive Ping Algorithm

- Adjusts the pulse distance(s) to prevent sampling during predicted interference regions.
- User specified interval (once, every minute, every 10 minutes, etc.)
- The Adaptive ping algorithm isn't perfect, otherwise we would use it all the time.
  - It still requires the user to specify a minimum velocity range.
  - It can move to Dual PRF operation too readily.
- When it works, it works well.

Bottom Distance Measurements

- **Specify a search range**
- **Sample rate can be 1-10 Hz.**
- **Maximum range of 3.5 m subdivided into a maximum of 1000 cells.**
- **Adjustable cell size if a wide distance range is expected.**
- **Gain reduction to compensate for very loud boundary echoes.**
- **Range compensation to account for attenuation with distance.**



Bottom Distance Measurements

- A velocity ensemble with reduced ping pairs provides time for bottom distance measurement.
- Velocity sample rate is maintained.
  - Bottom distance sample rate must be less than 1/3 the velocity sample rate.
- Bottom peak amplitude should be less than -15dB.
  - A saturated peak cuts off the actual peak, leading to errors in distance measurement.

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Bottom Distance Measurements

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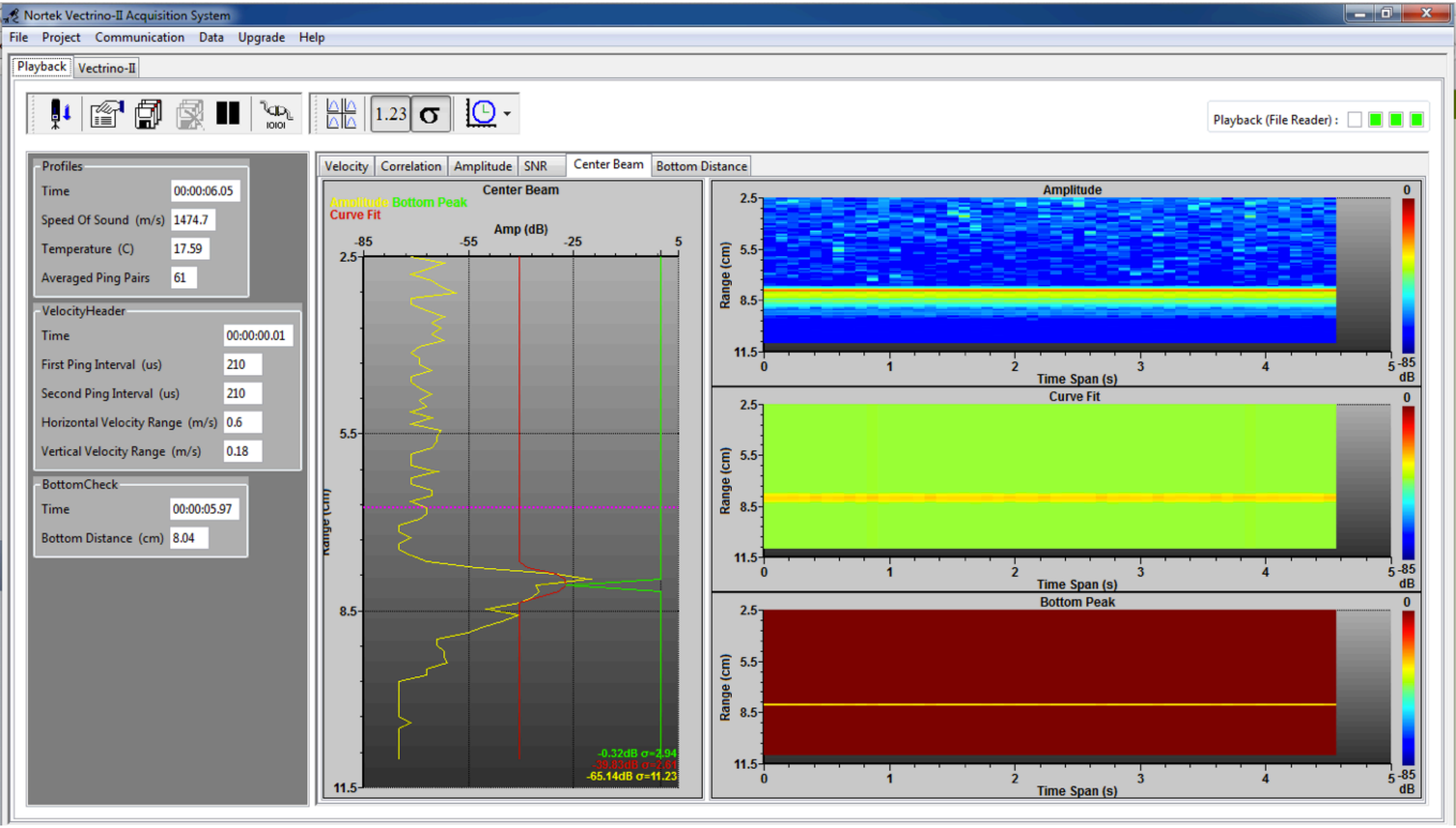

Peak Saturation

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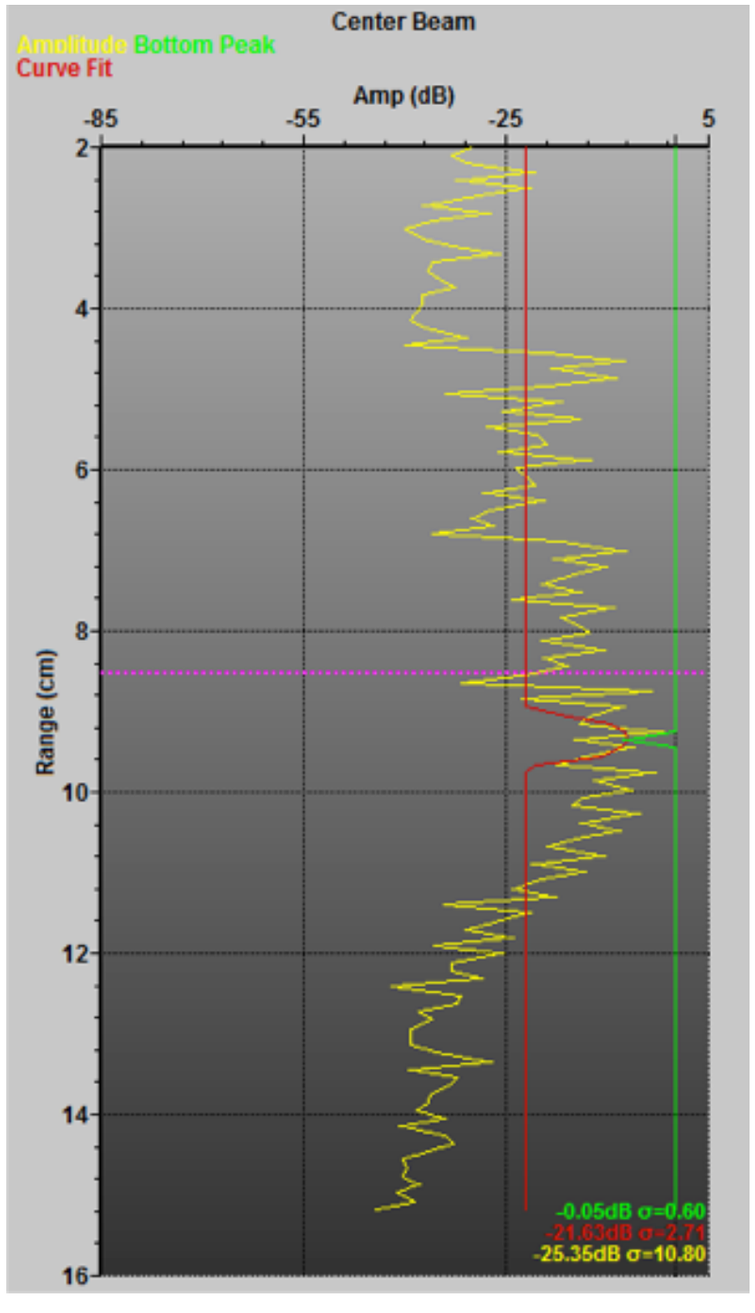
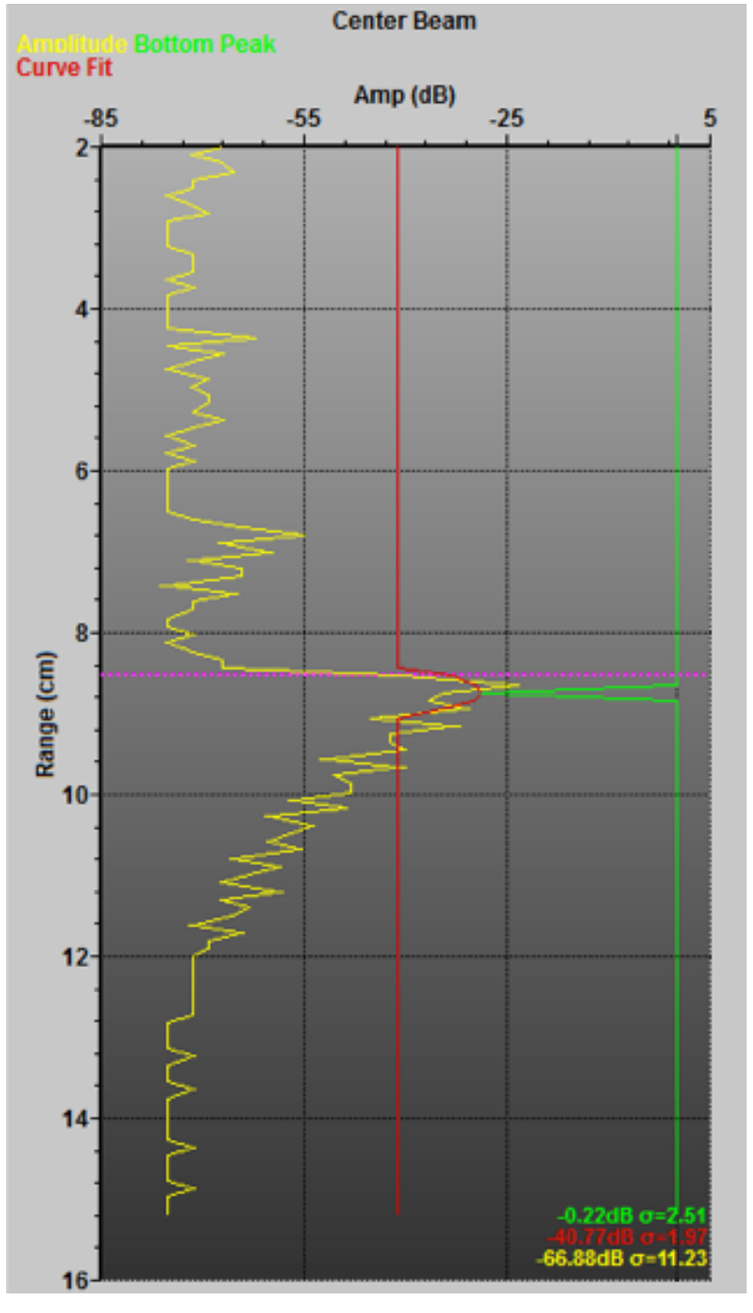


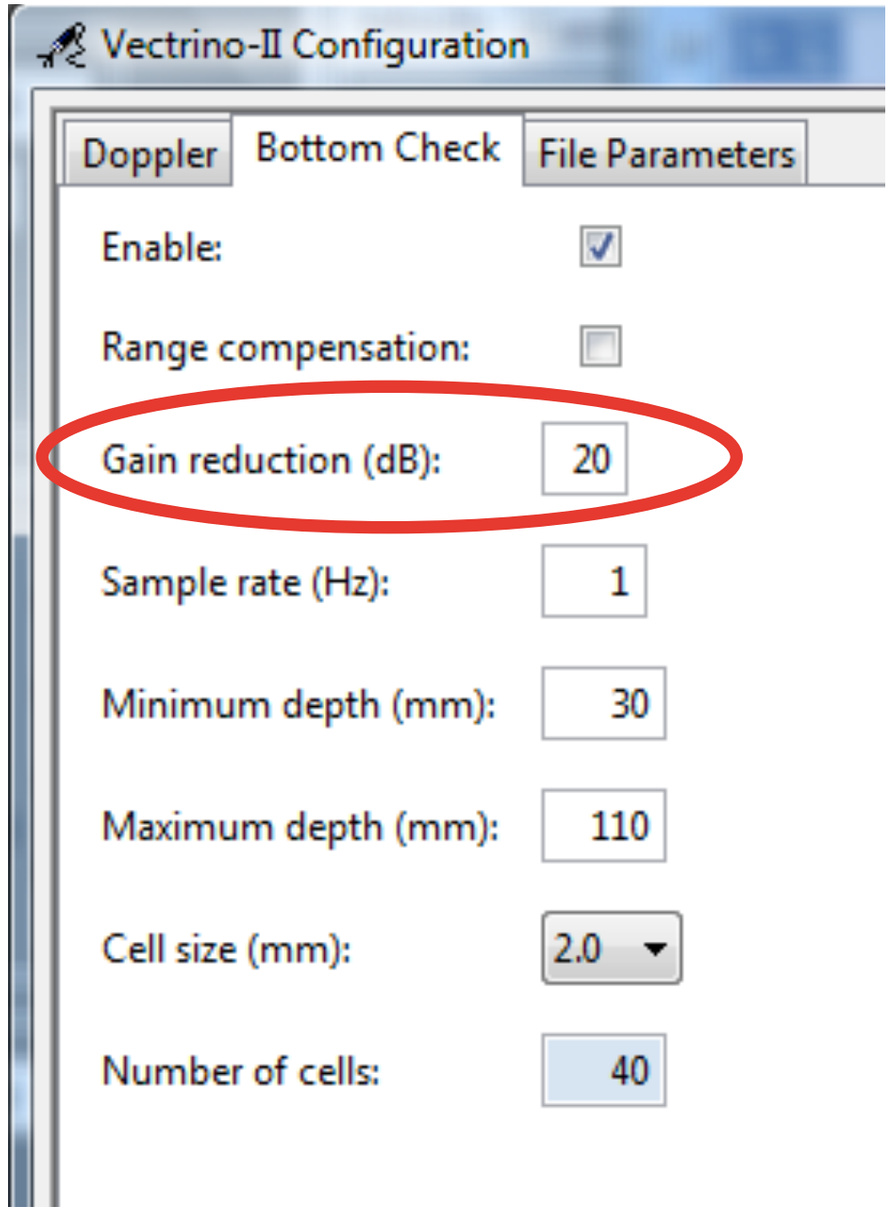
Gain Reduction = 10dB

Glass Bottomed Flume



Gain Reduction = 50dB

Gain Reduction



User Software: Data Collection

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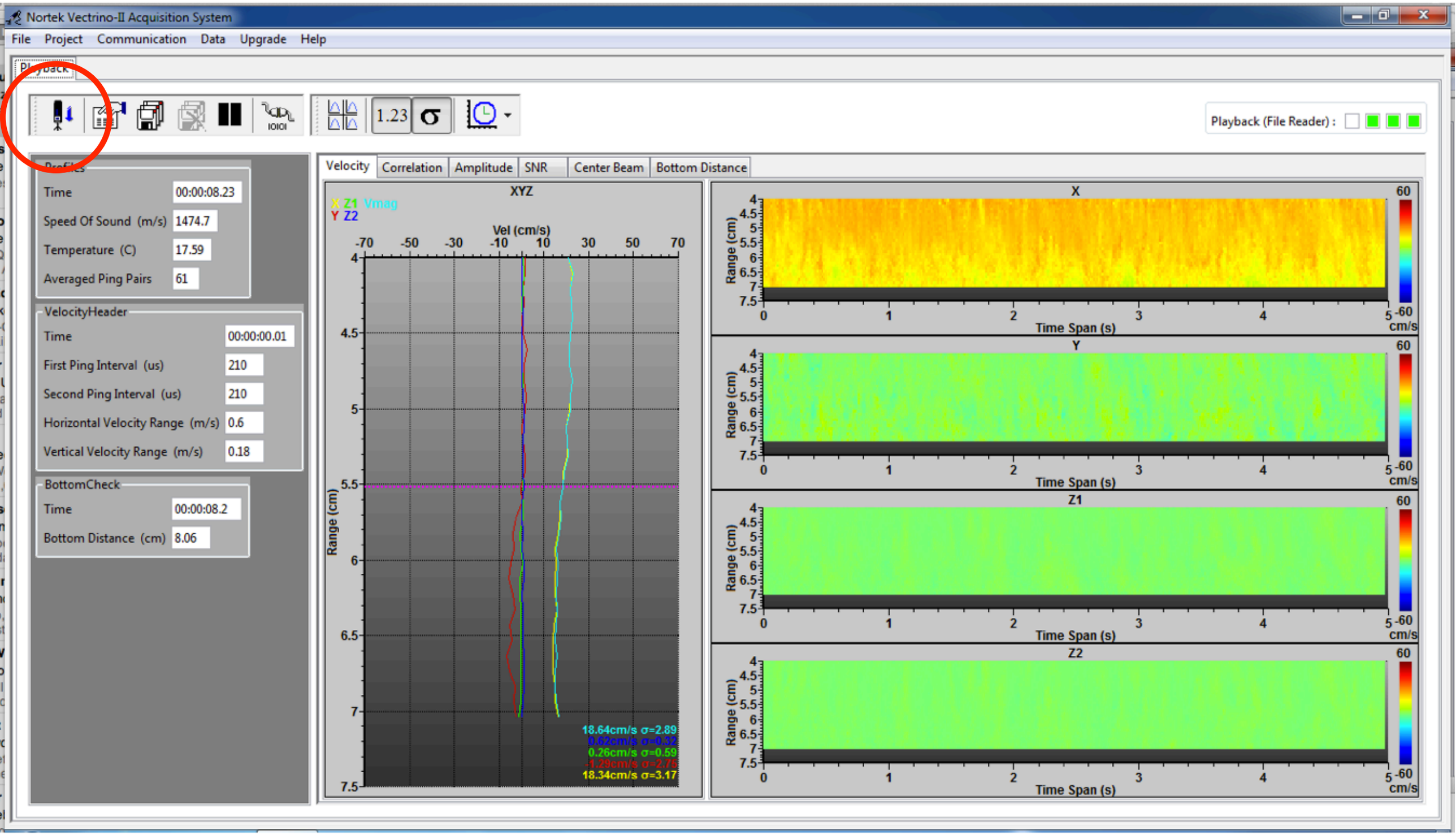

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Vectrino Profiler data

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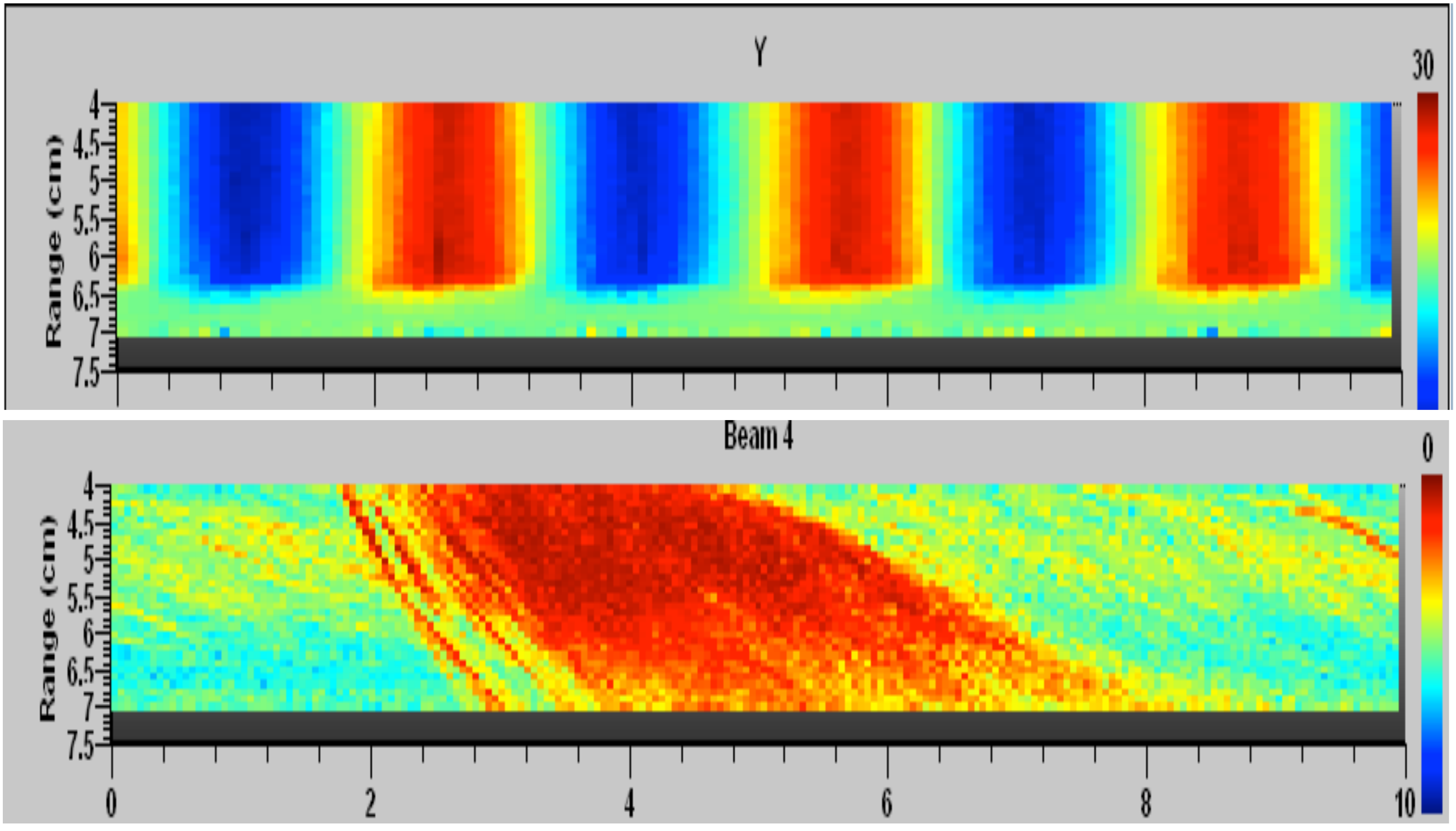

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Applications

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Field experiment with Vectrino II at UNC – Chapel Hill

Wave Flume

Demonstration
experiment in wave flume at
University of Quebec, INRS-ETE

Bottom Conditions

Bottom conditions in field experiment at UNC – Chapel Hill

Bottom Boundary Layer Studies

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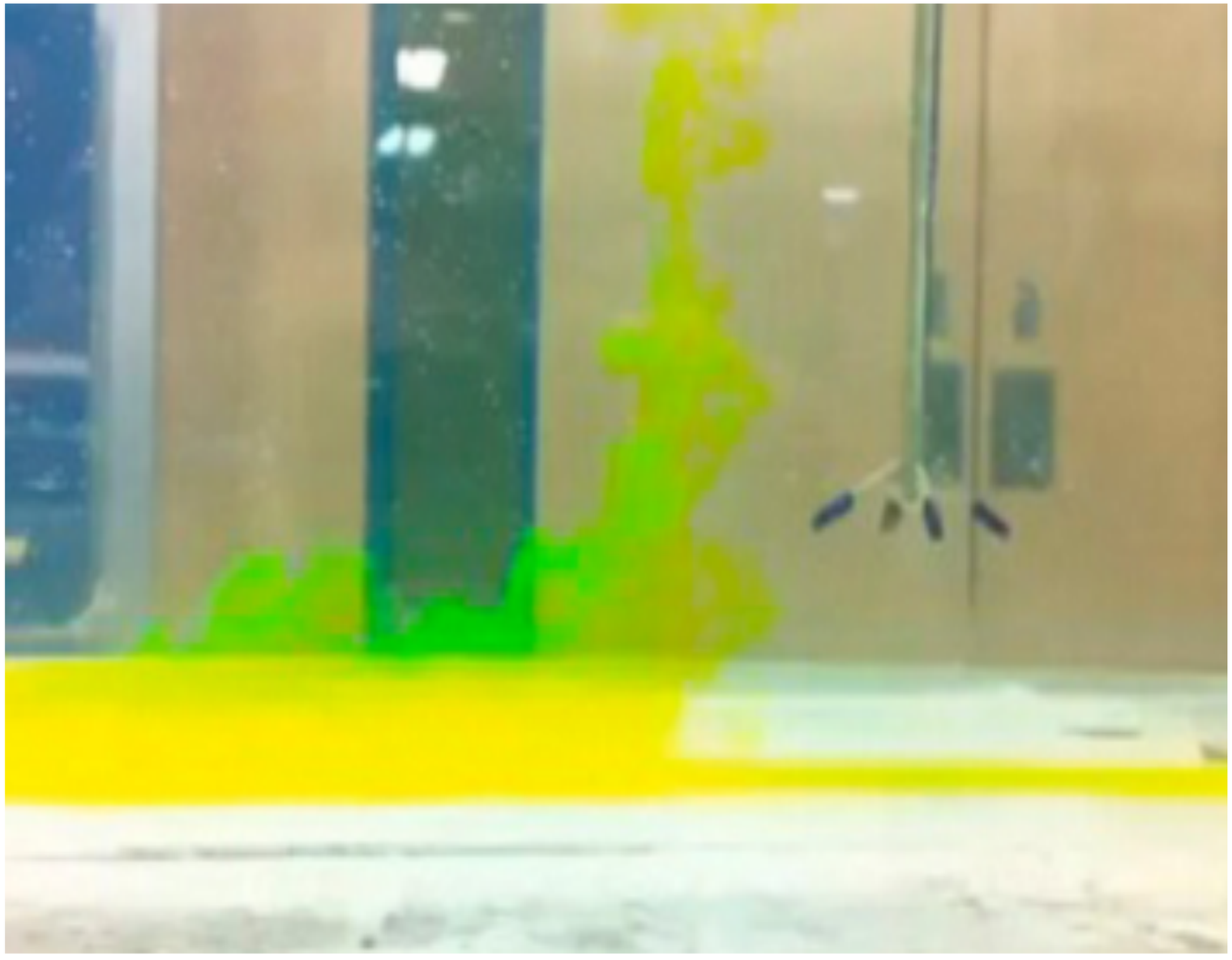

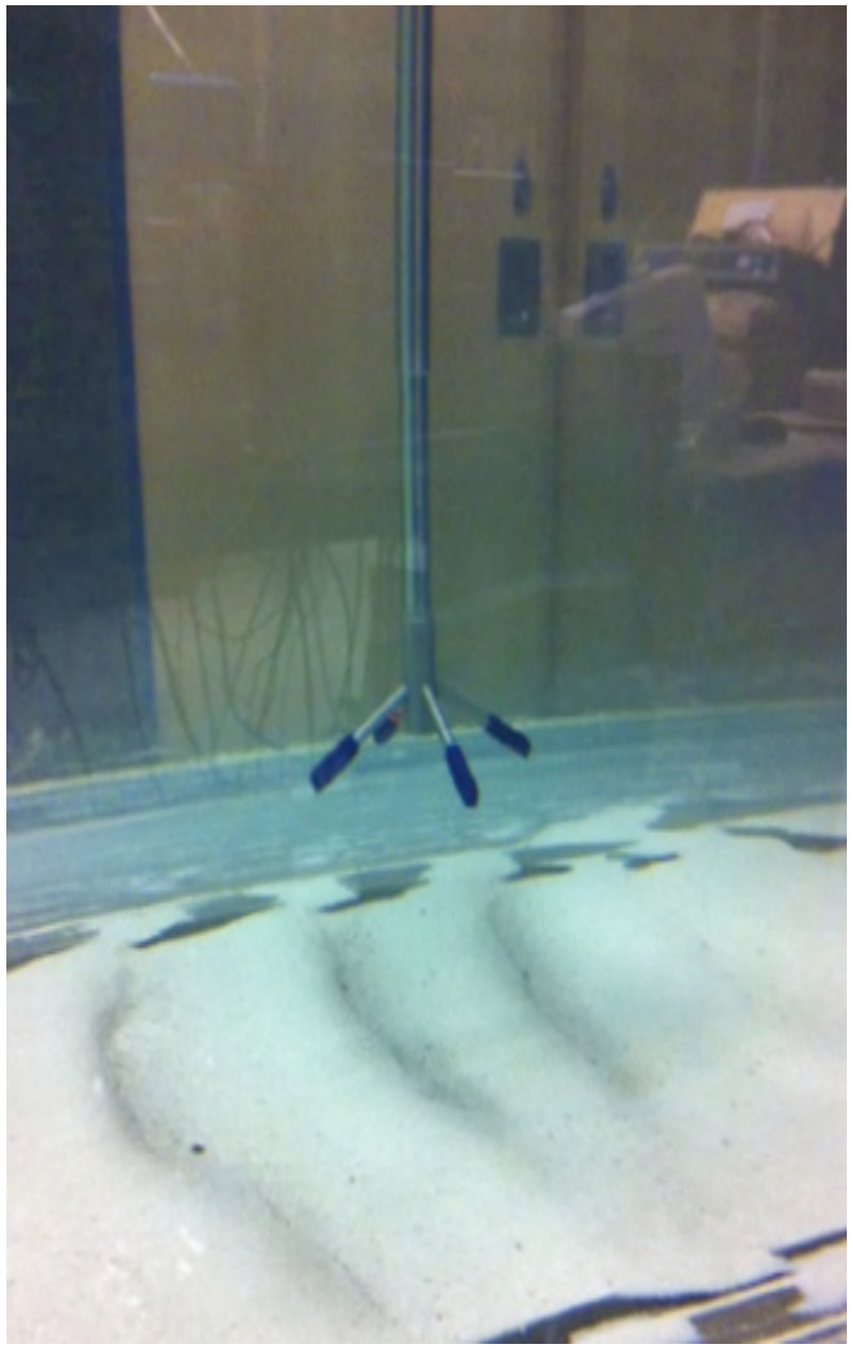

SYNC modes

SYNC on start
Start data collection when SYNC pulse received
Combine with "File Completion / New file (stop and restart)" to create a new data file when SYNC received
SYNC on measure
Completes a velocity measurement when SYNC pulse received
Master (Vectrino)
Output SYNC pulse when measurement completed
Master (Other)
Output SYNC pulse in middle of measurement

Questions?