# A multi-angle acoustic scattering apparatus for zooplankton and fish

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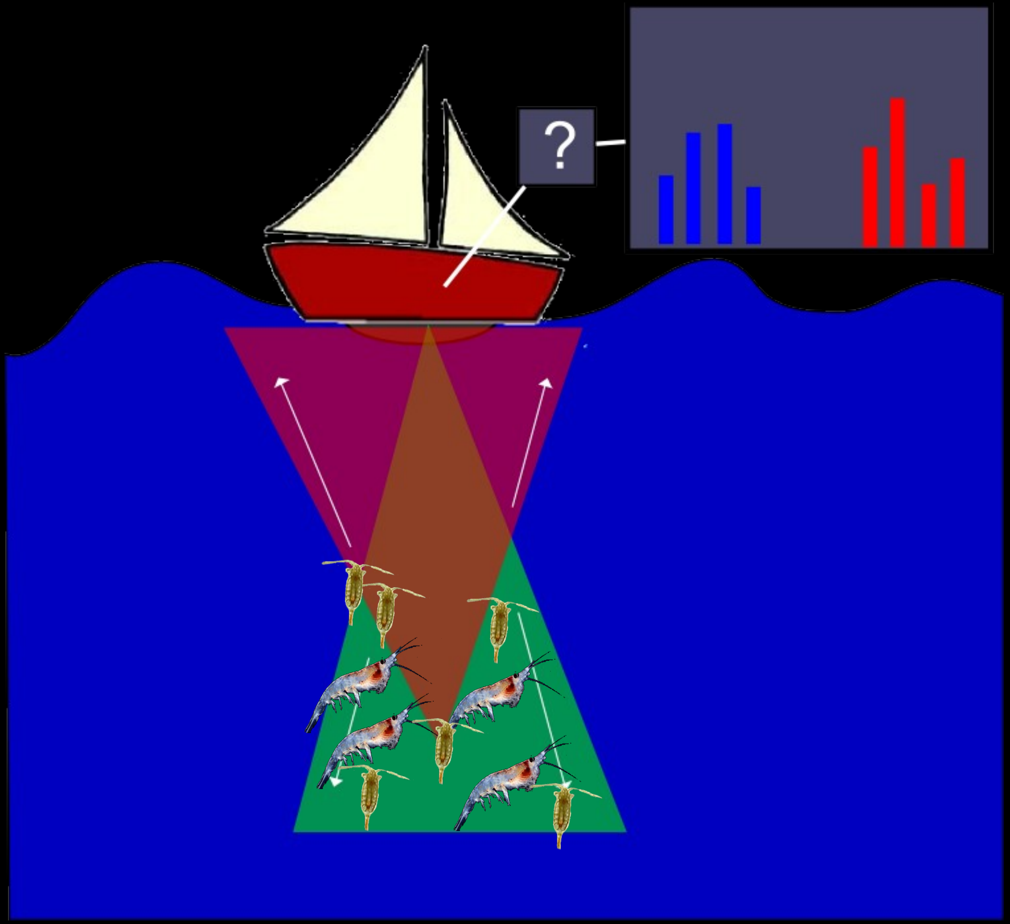
AOS Seminar 2007

# Outline

- Background and motivation
  - Previous studies, backscatter modeling, and the application to in situ systems.
- Design of a multi-angle laboratory scattering system
  - Tank, acoustics, reverberation, calibration, animal behavior.
- Preliminary data.
- Work for future.

# Background: Motivation

- Use acoustics to survey marine animal populations.
- Empirical forward modeling for target strength estimation.
- Acoustic classification studies.
- How can we solve the inverse problem?



# Background: Forward modeling experiments

Measure scatter from animals and build a model

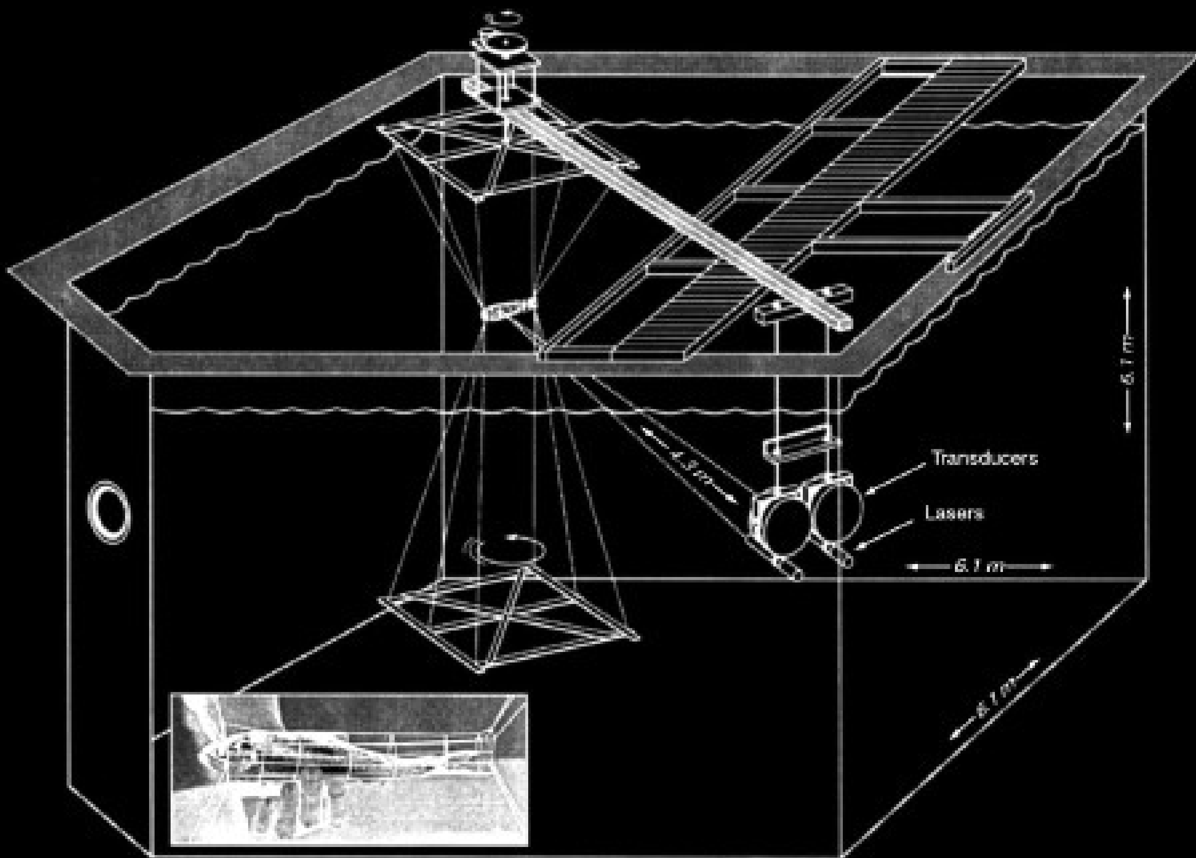



FIG. 6. Schematic of the laboratory system used for measuring acoustic backscattering by live, individual fish as a function of angle of orientation and frequency: tank, transducers, lasers used for alignment, stepper motor to rotate the animal in the acoustic beam, and acoustically transparent tether system. The transducers and rotation frame were drawn disproportionately larger than the tank to highlight them. Also, the photograph of the harness, shown in the inset, was enhanced so the thin monofilament could be illustrated.

Reeder et. al 2004

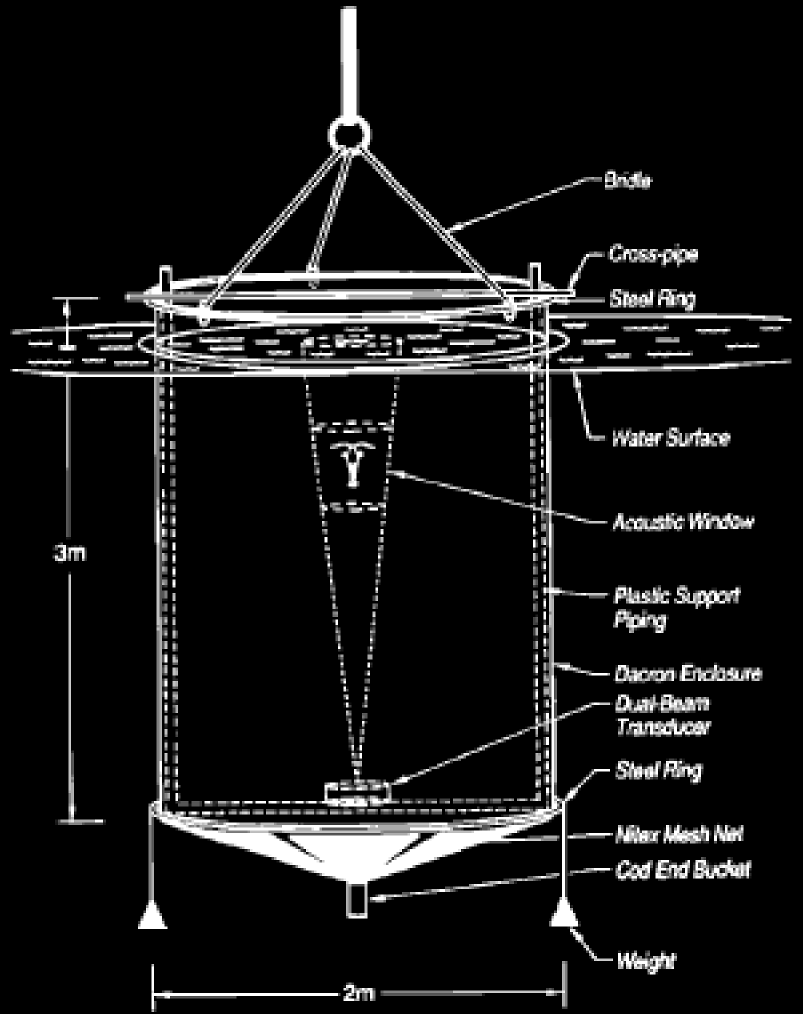
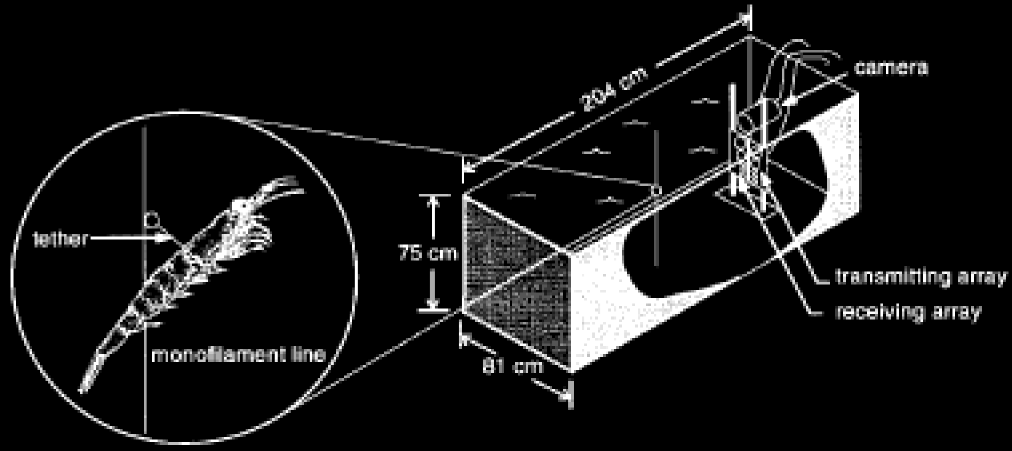


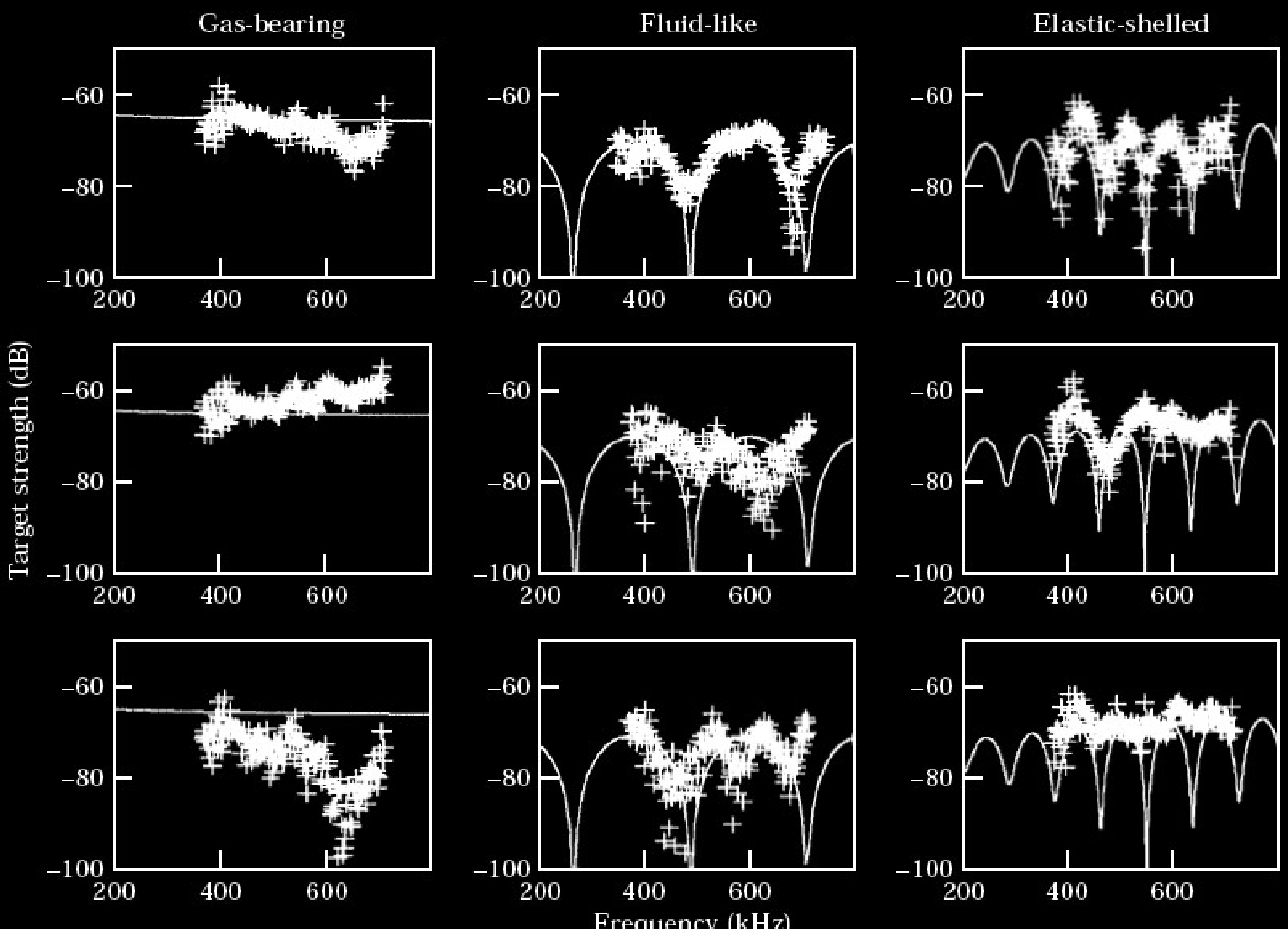

FIG. 2. Schematic drawing of the Friday Harbor Experimental Chamber. The enclosure was deployed off the laboratory dock. See text for details.




Traykovski et. al 1998

Wiebe et. al 1990

# Background: Acoustic Classification



# Multiple angles

- More observations of scattering could reduce uncertainty about scatter size, shape and taxa.
- In some cases, the additional observations can be obtained without substantial cost (just add a few more trandsucers and channels)
- Current surveys limited in many cases (fish, krill) by scatterer orientation.

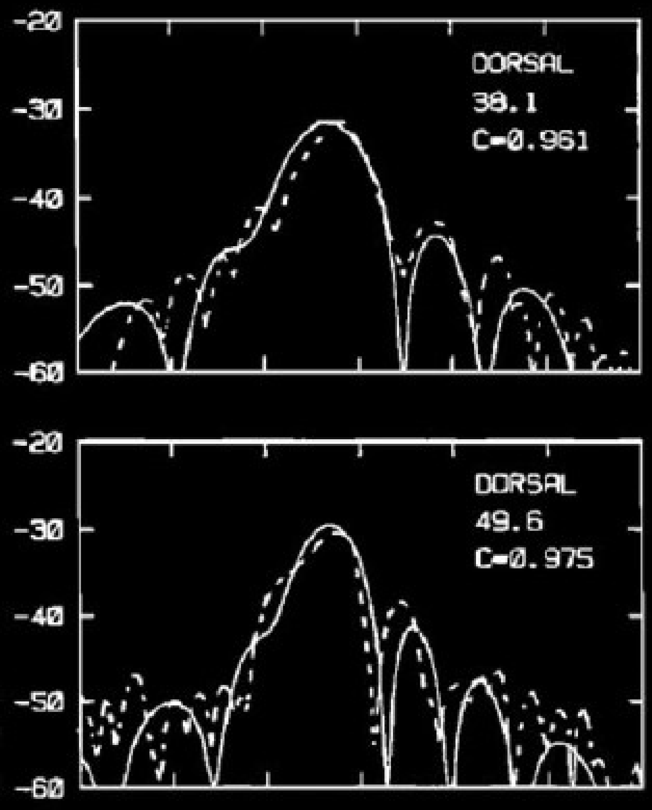
# Motivation: Time varying scatter

- Previously all studies have only considered stationary targets.
- For classification, including the dynamics could be helpful (different swimming speed, behavior).
- This requires the ability to track multiple targets, as well as good calibration.

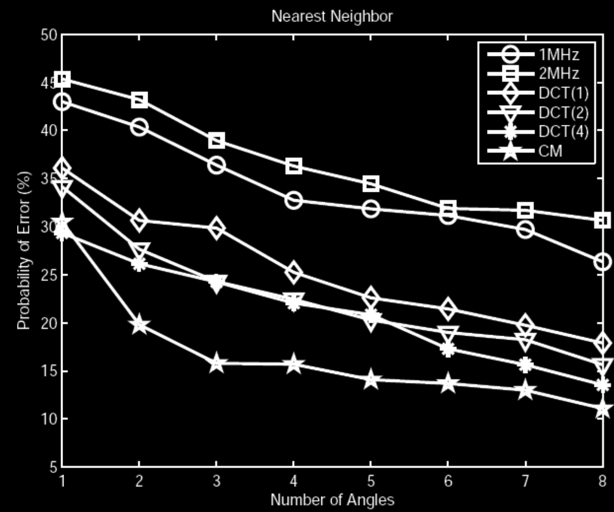
# Previous multi-angle studies

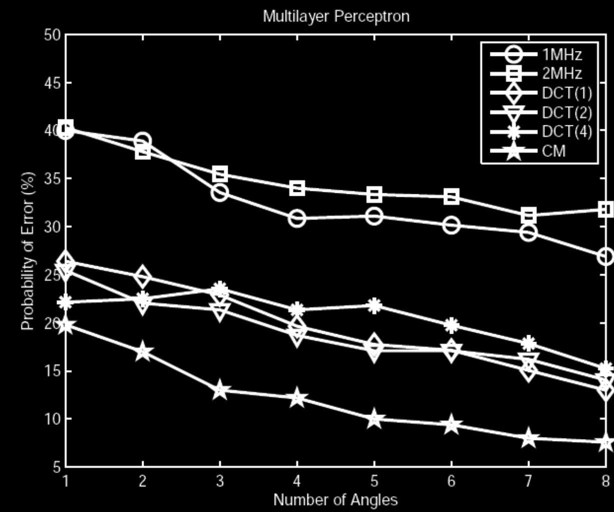
Incorporating additional angles can improve estimates of animal length, or taxa.

Estimating fish bladder length




Classifying zooplankton

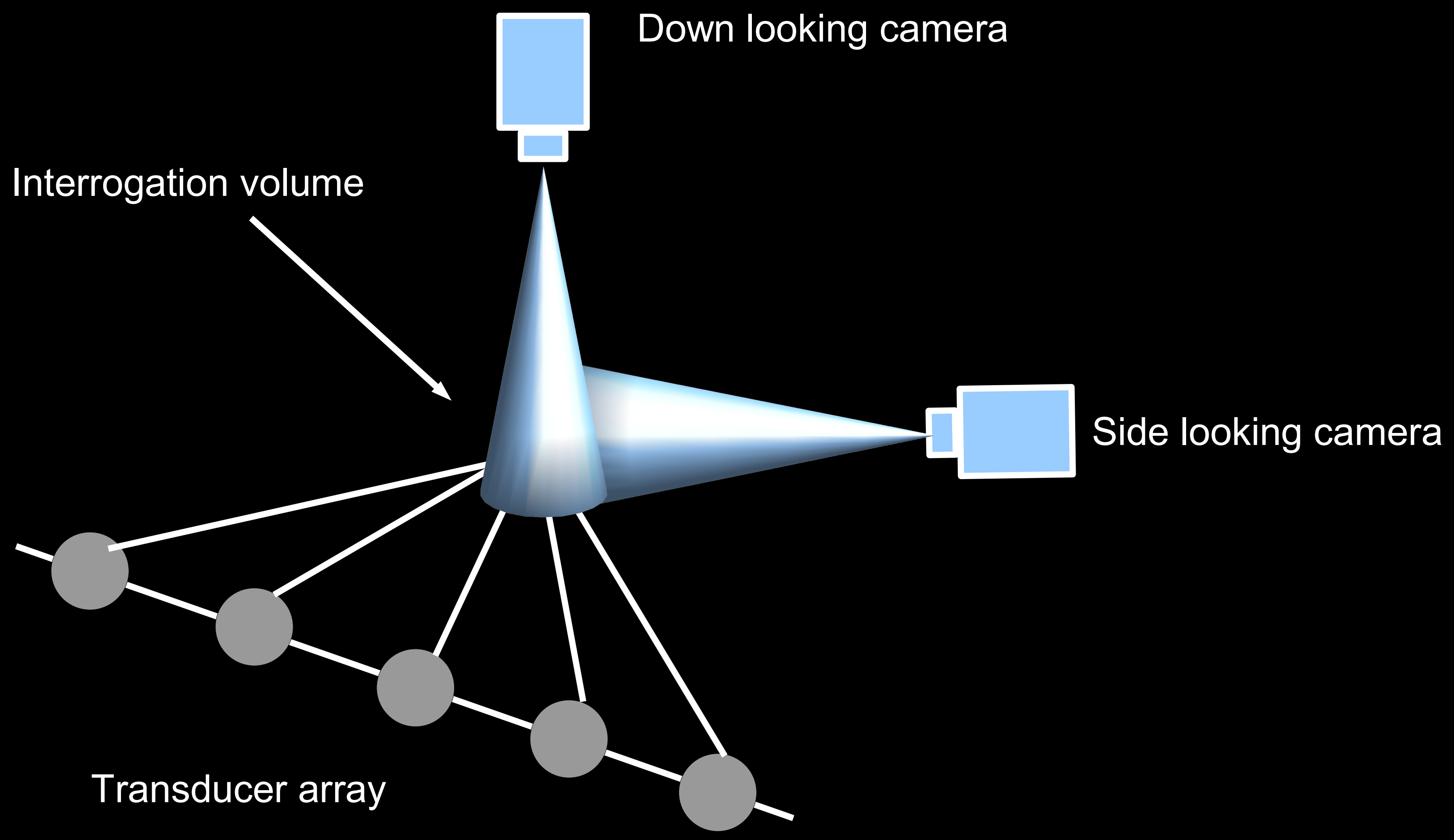


# Experimental overview

- Test simulation results on live animals.
- Collect the first multi-angle data set for zooplankton and fish.
- Observe dynamic animals (minimal thethers).
- Study realistic scattering environments (multiple targets, water motion).
- Ground truth with stereo video.

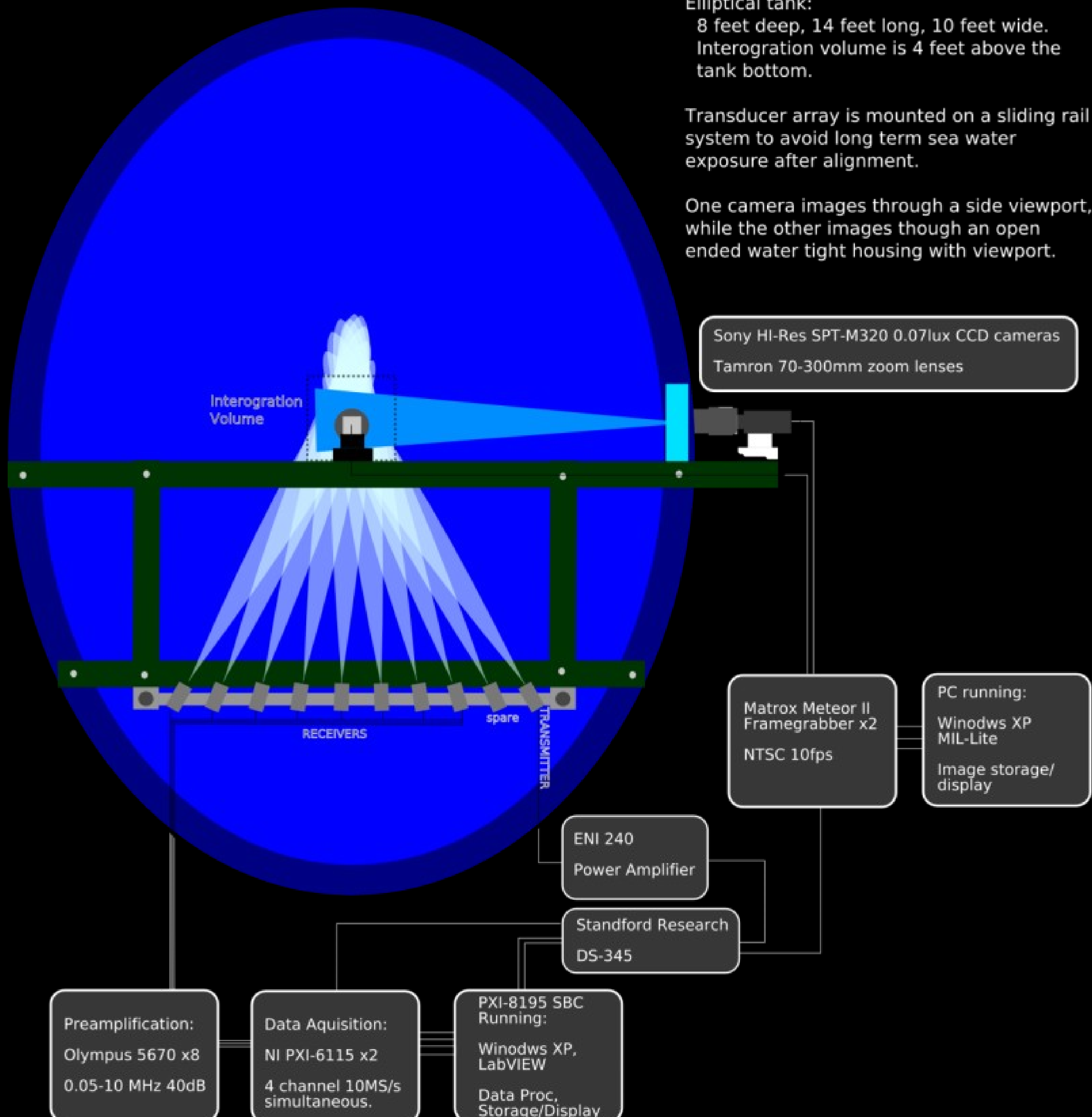
# Experiment concept

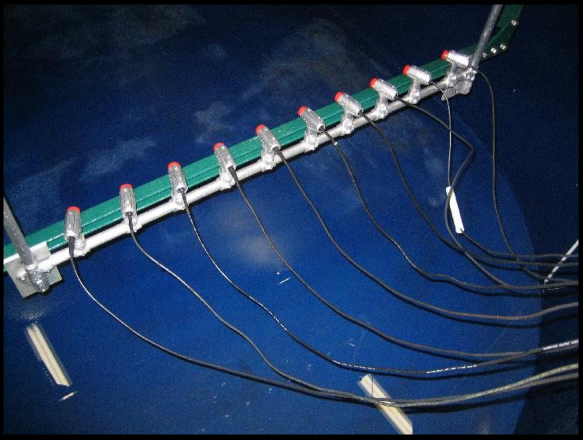


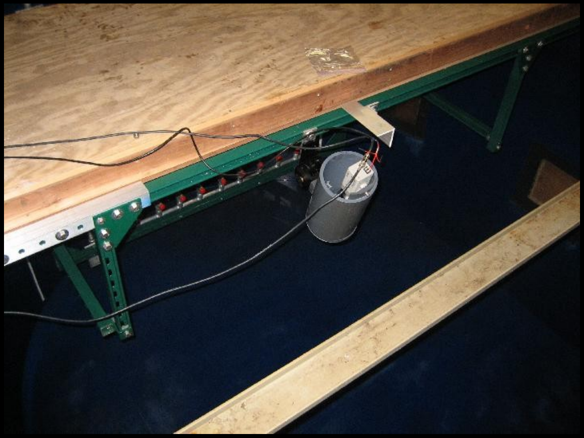
Elliptical tank:
8 feet deep, 14 feet long, 10 feet wide.
Interogration volume is 4 feet above the tank bottom.

Transducer array is mounted on a sliding rail system to avoid long term sea water exposure after alignment.

One camera images through a side viewport, while the other images though an open ended water tight housing with viewport.



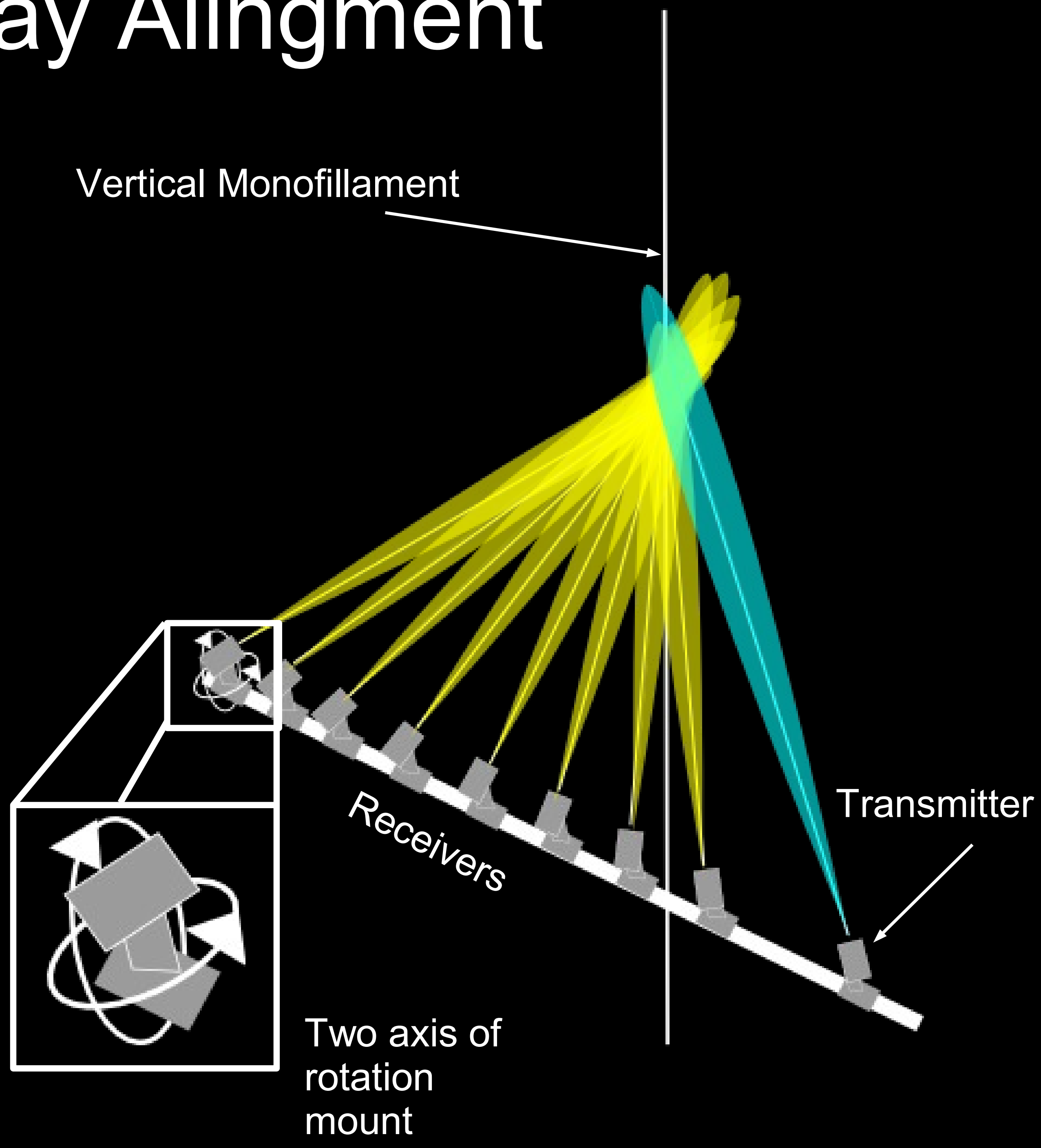


# Features of the system

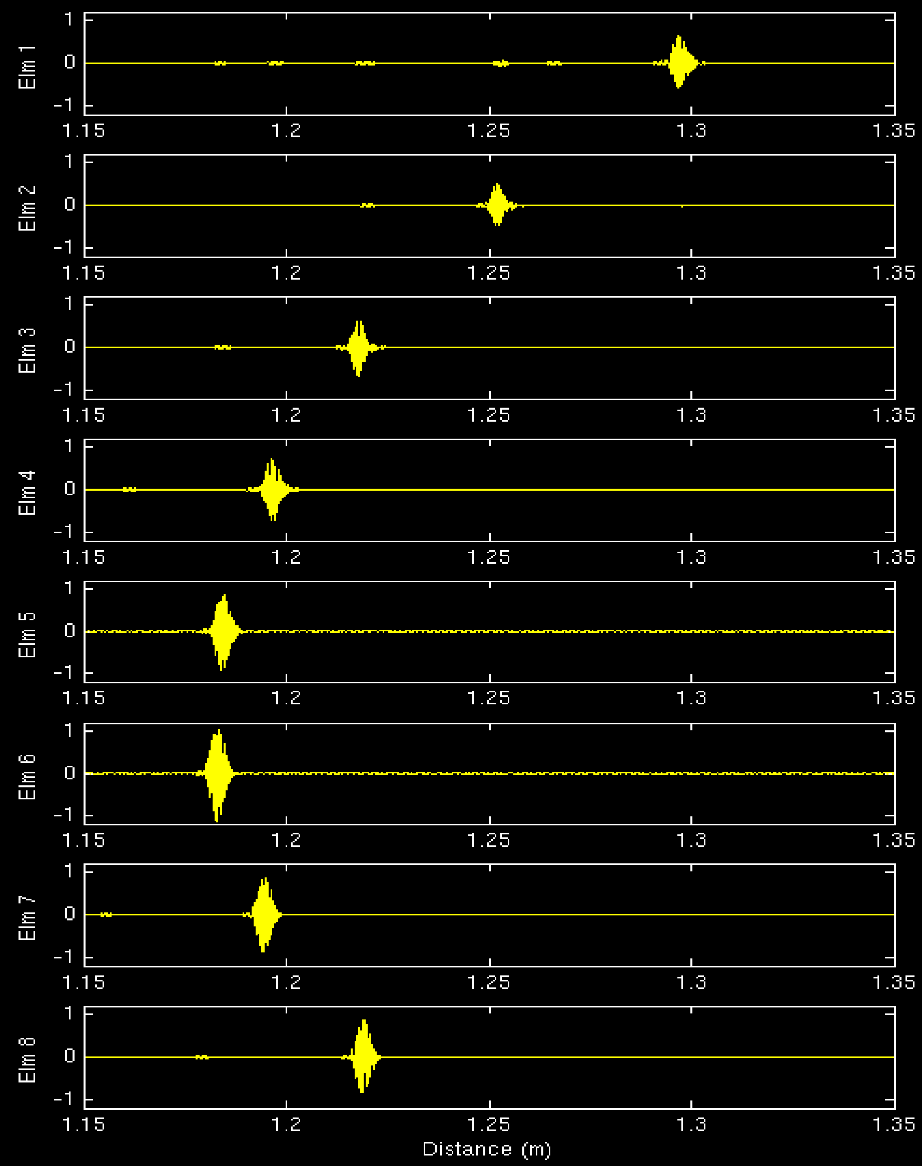
- One transmitter, eight receivers.
- Rigid array on sliding rail system.
- Cameras mounted on three-axis telescope mounts.
- Broad band transducers (0.25-3.5MHz).
- Arbitrary waveform generation.
- Laser Illumination.

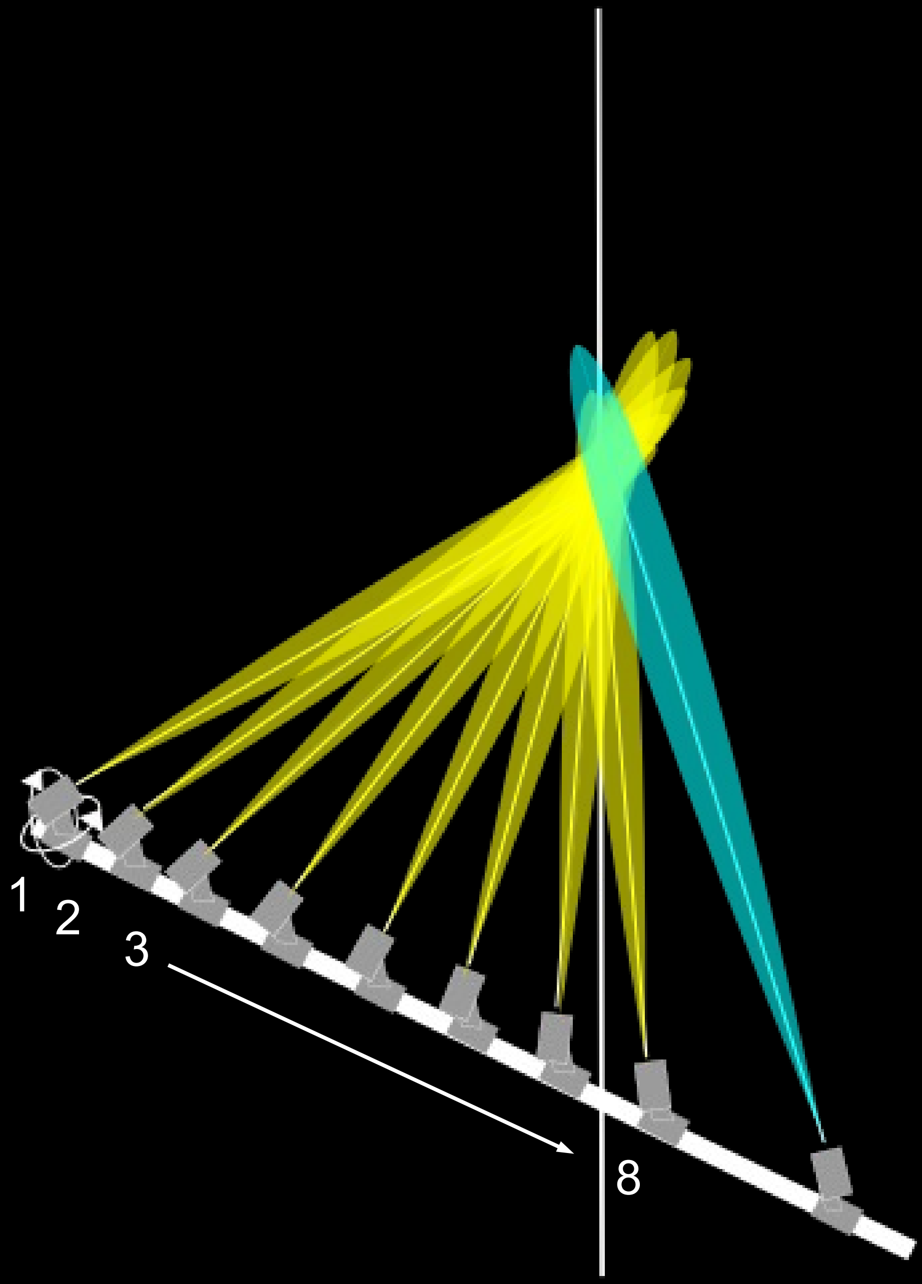
# Array Alingment

- Initial alignment using a laser pointer.
- Tank filled half way, and the system turned on.
- With real-time display of data, rotate each receiver until max return.
- Rotate transmitter to max all returns.



# Reflection data from cal sphere



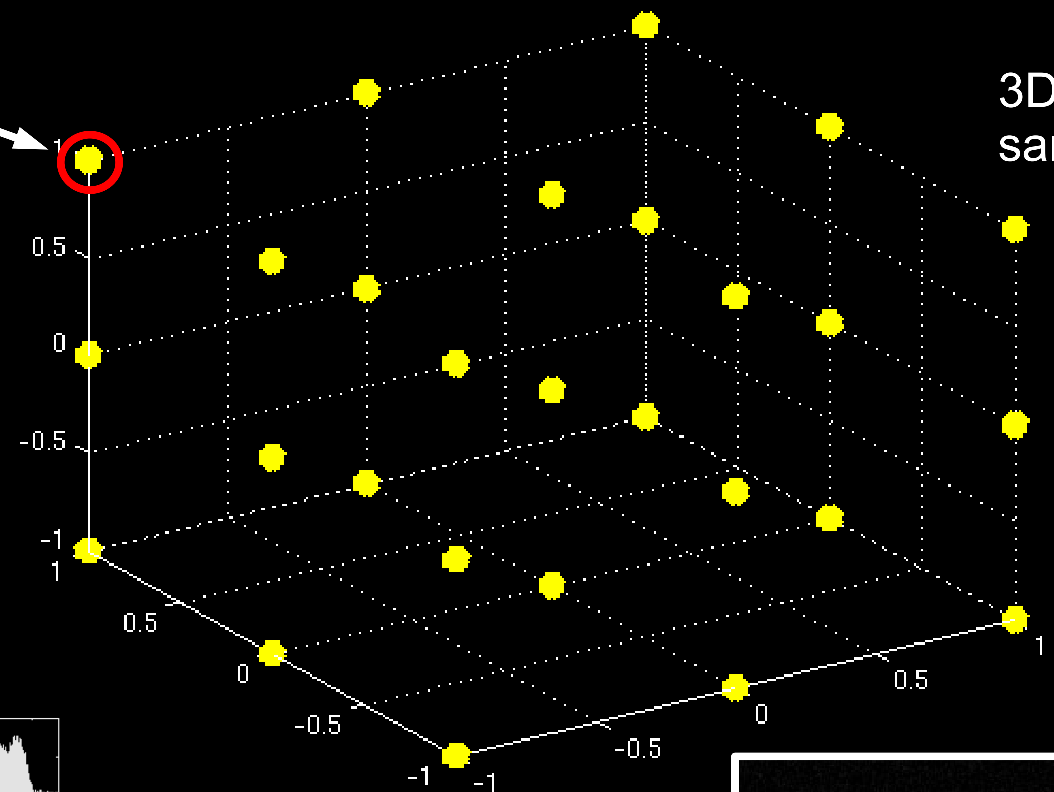



# System Calibration (first try)

- Estimate 3D location of scatterer from image pair.
- Map the acoustic field into image planes.
- Convert echo voltage to target strength at each frequency.

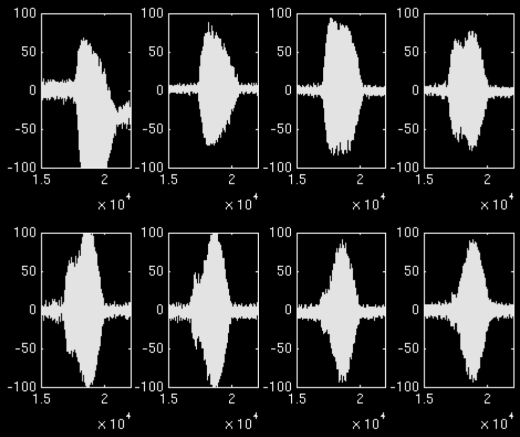
# Calibration concept

Calibrated target positions

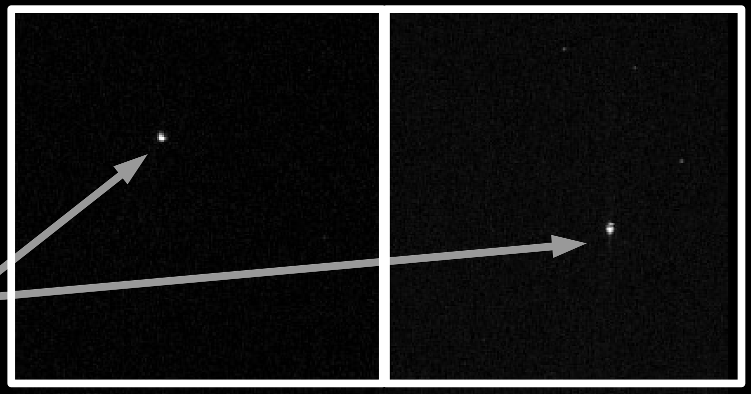



3D space in the sample volume

Echoes on each receiver



Projection of target into each image



# Calibration Movie

# 3D Target localization using image data

From the image data, and grid points, extract mapping functions from 3D to each image

$$\boldsymbol{X}^1 = F^1(\boldsymbol{x}) \qquad \boldsymbol{X}^2 = F^2(\boldsymbol{x})$$

Mapping functions computed using a neural network built using Netlab

$$X_i^j = \hat{F}_i^j(\boldsymbol{x}) = U\left(\sum_{k=0}^{K} \tilde{w}_{i,k} V\left(\sum_{l=0}^{3} w_{k,l} x_l\right)\right)$$

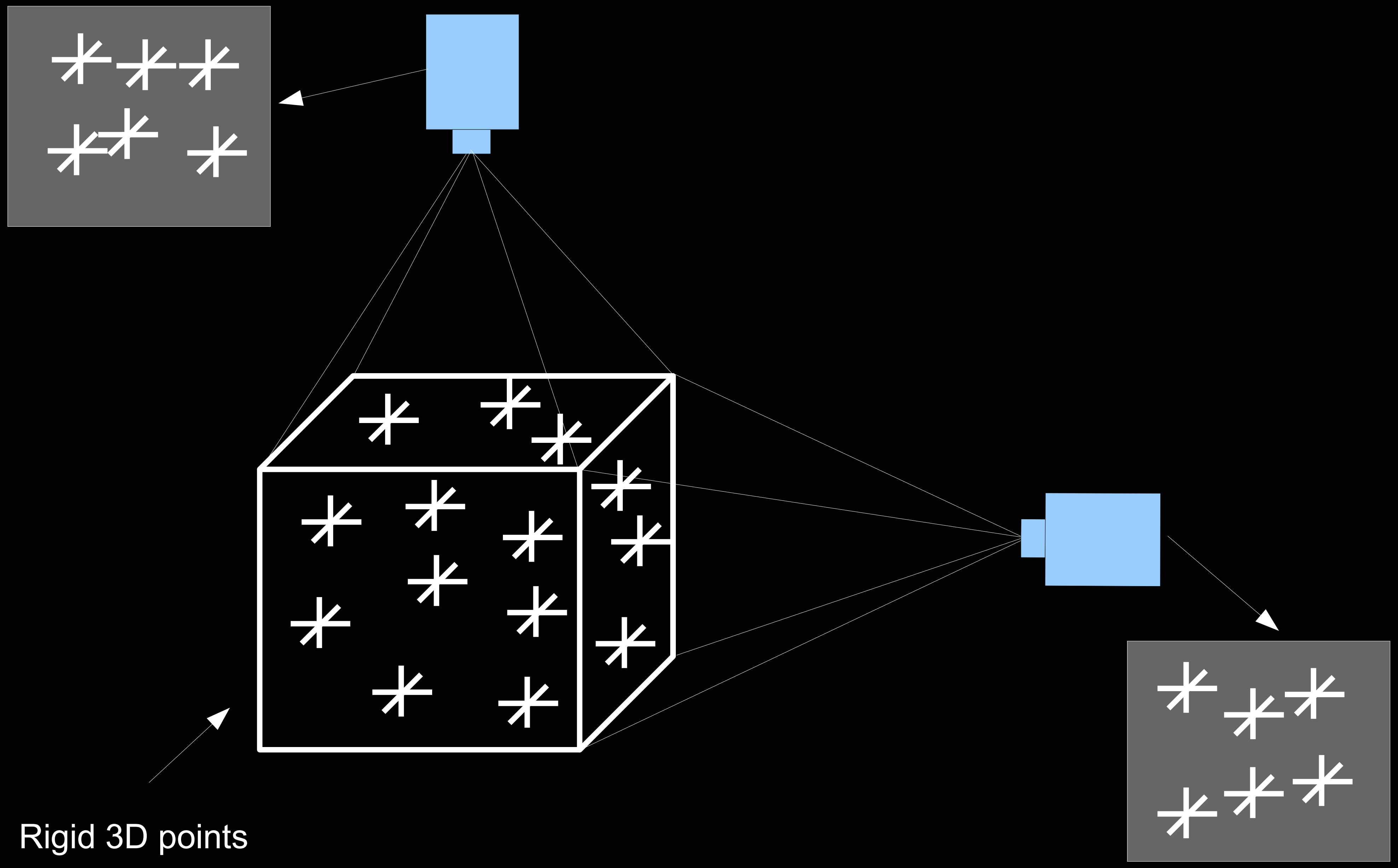
Then use both mapping functions and a very fine grid in 3D space to build a lookup table approximation to the inverse function

$$\hat{\boldsymbol{x}} = F^{-1}_{F_1, F_2}(\boldsymbol{X}_{\mathbf{1}}, \boldsymbol{X}_{\mathbf{2}})$$

# Issues with calibration

- Hanging ball method is too coarse for estimating body pose from images.
- Sample grid is too small.
- Effect of the tether may bias target strength estimates.
- Like to have more automation.

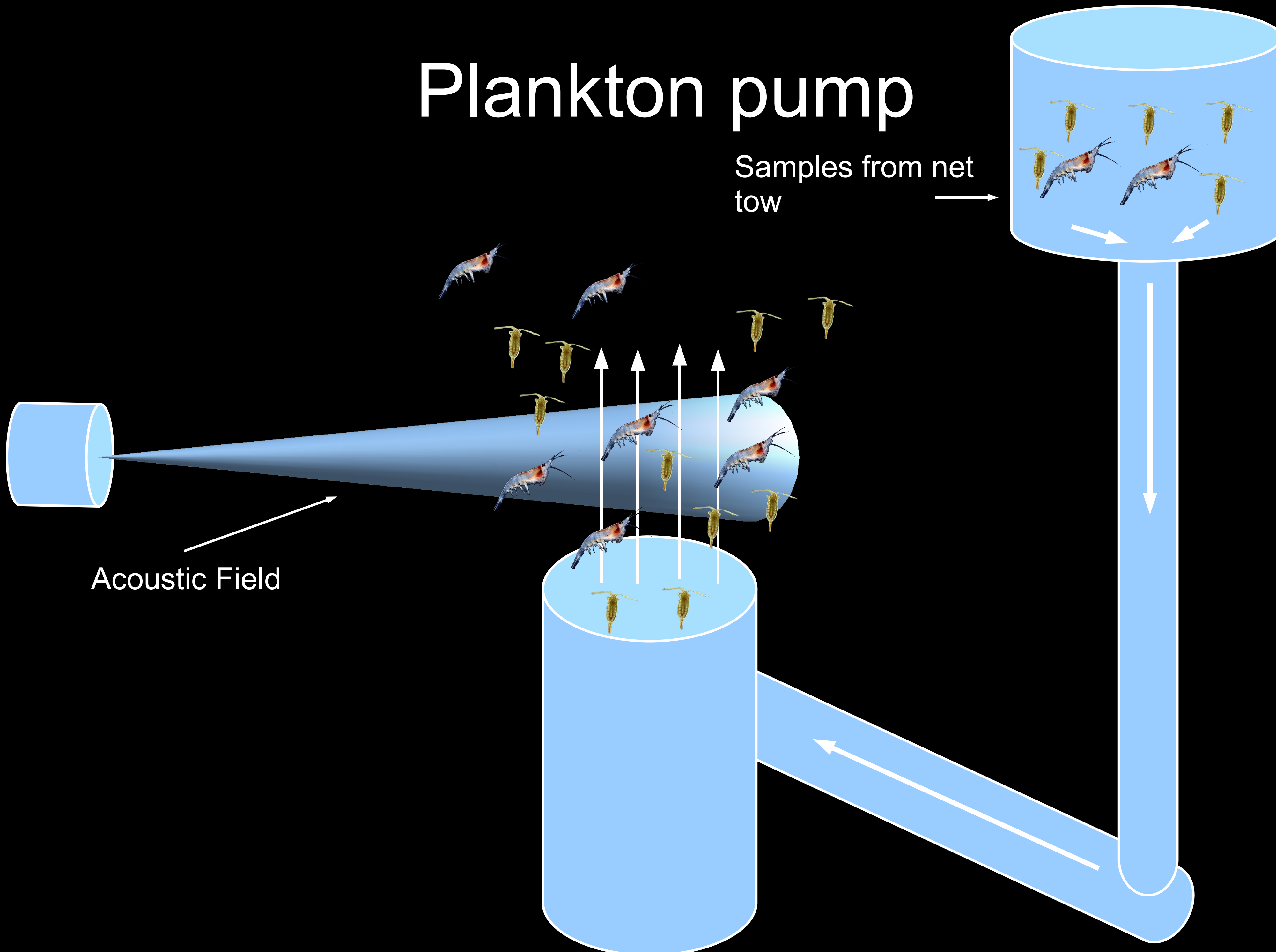
# An improved calibration?



# Dealing with live animals

- A big tank with a small field of view means big problems!
- For the small scatterers, tethers typically corrupt the echo.
- For larger scatters, behavior will typically keep them away from the field of view.
- Two different solutions were developed in to solve these issues.

# Plankton pump

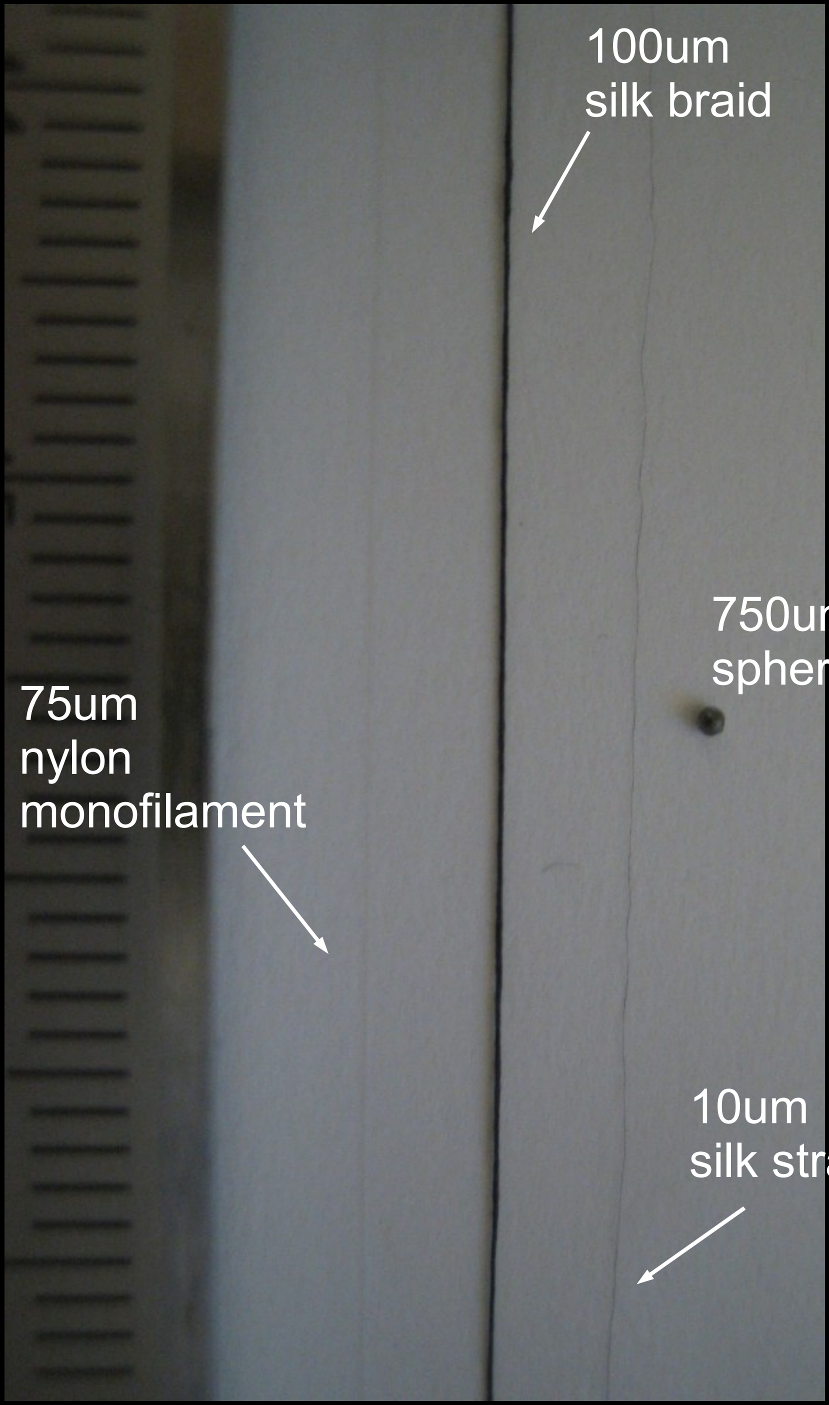


# Plankton Pump

- Realistic data, with water motion, free swimming animals, diverse scatterers.
- Easy and relatively fast.
- Dramatically increases encounter rate.
- Bubbles entrained in pipe system.
- To keep flow rate low, need to have a wide output, many animals lost.
- Strong swimmers typically swim away before being insonified.

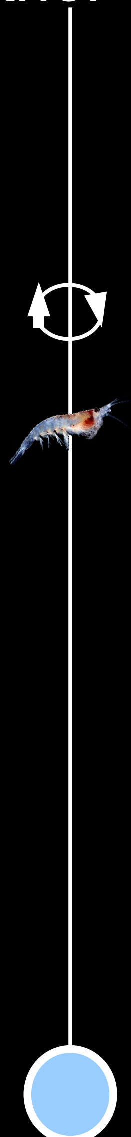
# Tethers

- Nylon monofilament or various diameters.
- Braided silk suture.
- Single silk strands.
- Thin slices of polyurethane.
- Thin Human hair.



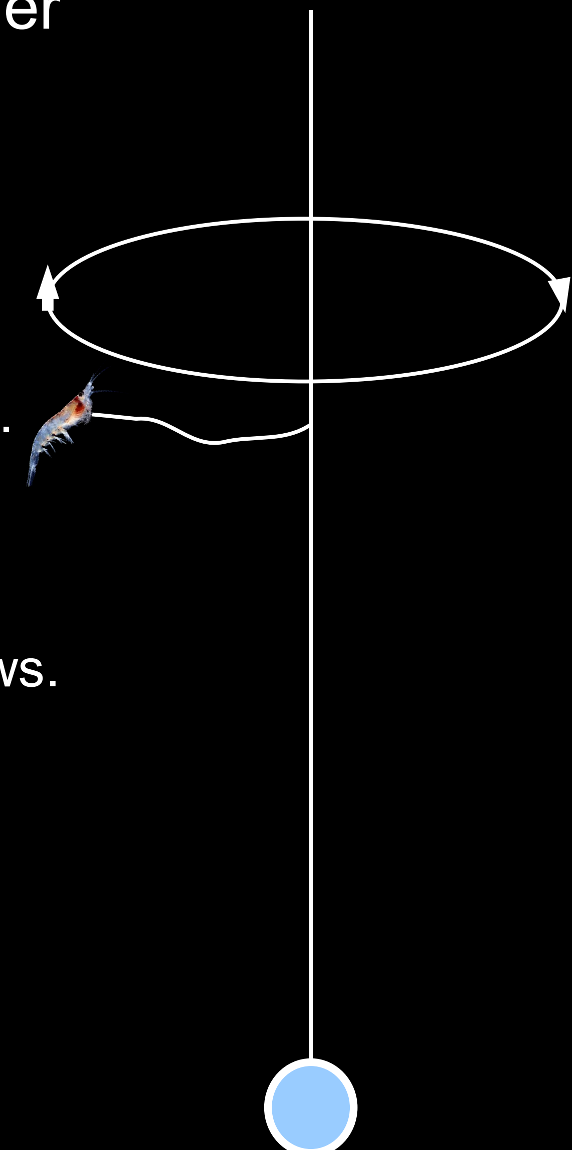
# Tether methods

## Static no swimming tether



- Nearly constant artifact from tether.
- Control over the animal's orientation.
- Full length of the tether must be in beam.
- No behavior.
- Animals may die quickly.

## Quasi-free swimming tether



- Animal can swim around.
- Main tether can be outside beam.
- Get some behavior.
- Tether is dynamic.
- Can wind up with a lot of the same views.

# Tether based methods

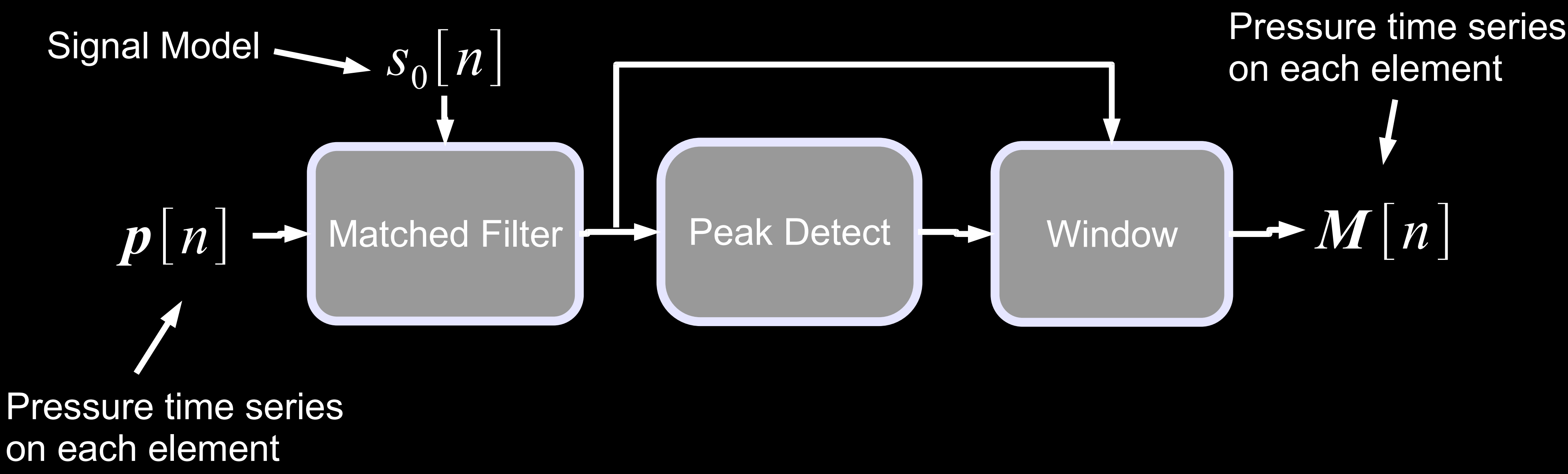
- Very hard to get an acoustically transparent tether at Mhz frequencies.
- Tethering animals is difficult.
- Cause atypical behavior.

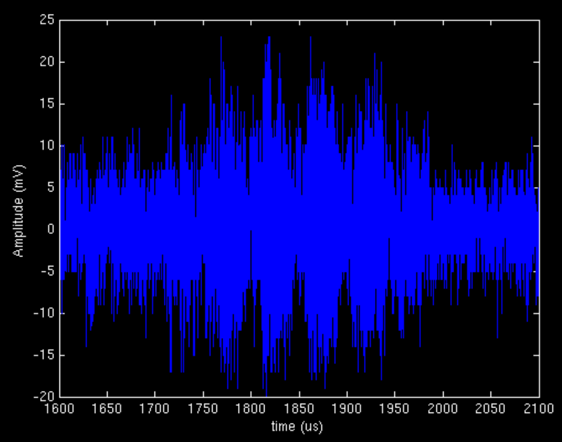
- Good localization.
- One scatter in the volume at a time.
- Much higher encounter rate.

# Preliminary data

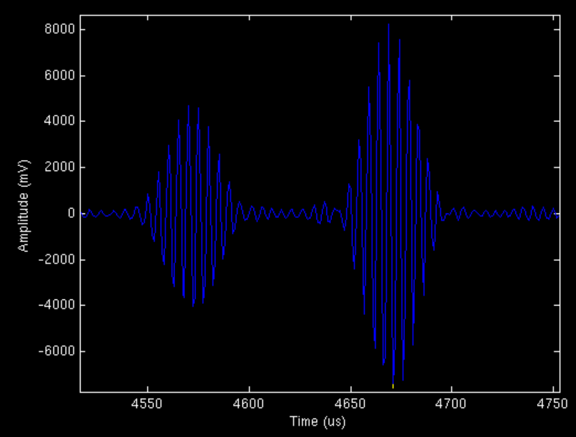
- Movies of animals moving through the field of view.
- Examining the variation in echo across the array.
- Ping series for zooplankton and fish data.

# Data Pre-processing

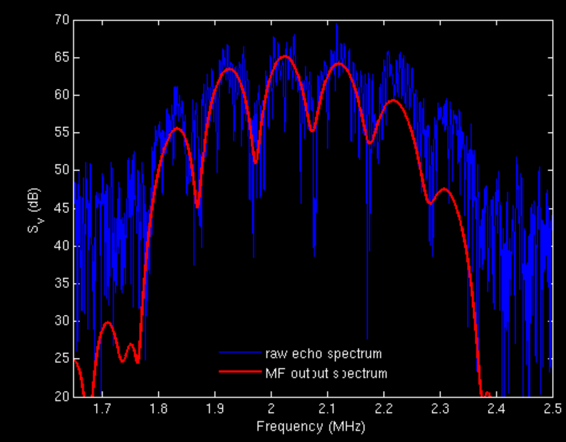



Raw Echo

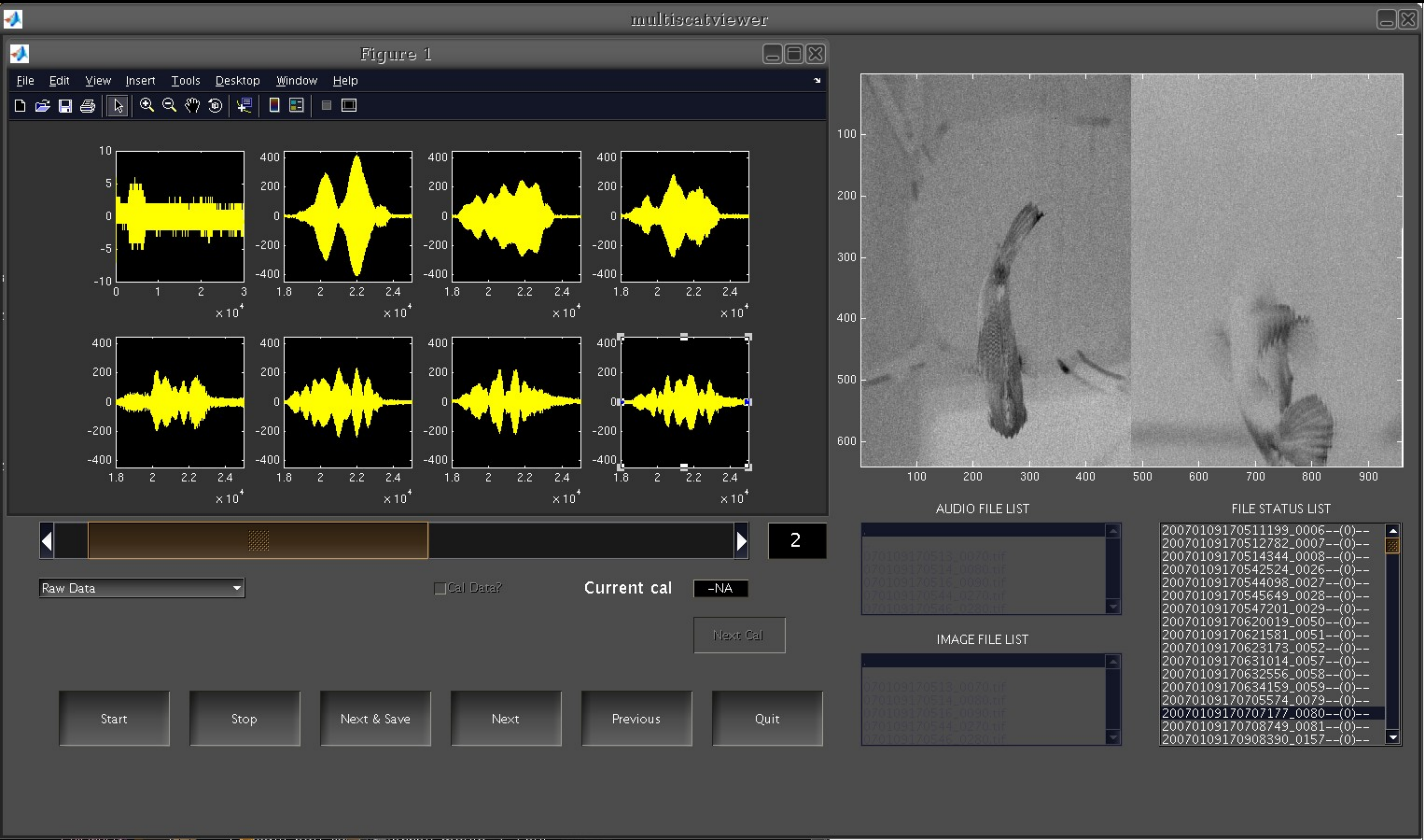



Windowed filter output



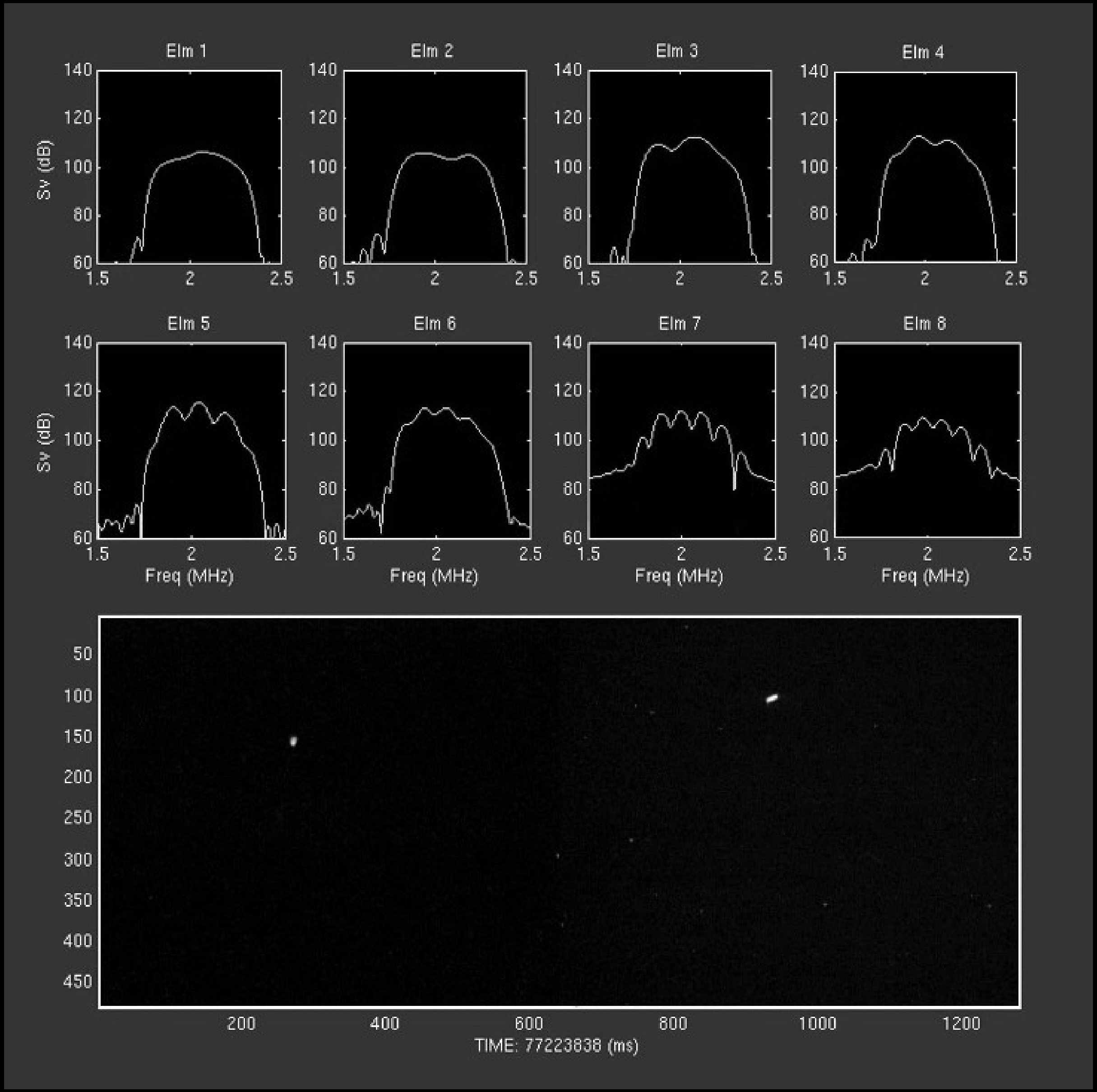

Spectral smoothing

# Data view software (matlab)



# Zooplankton movie

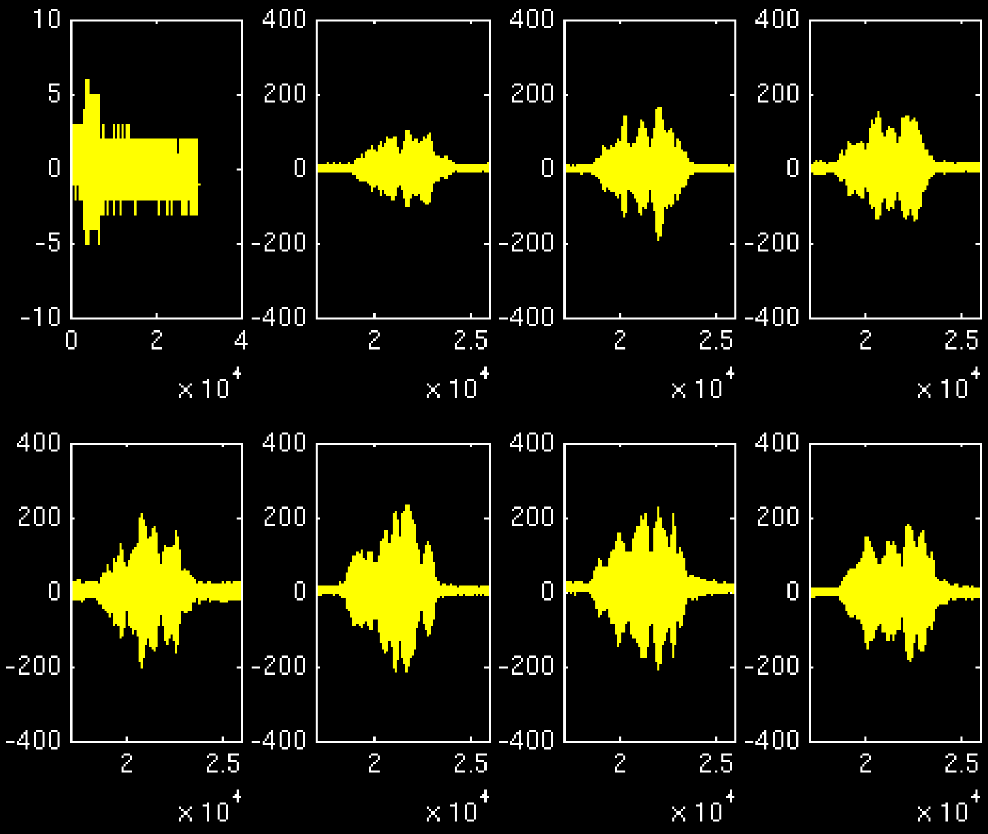
# Interesting variations across the array



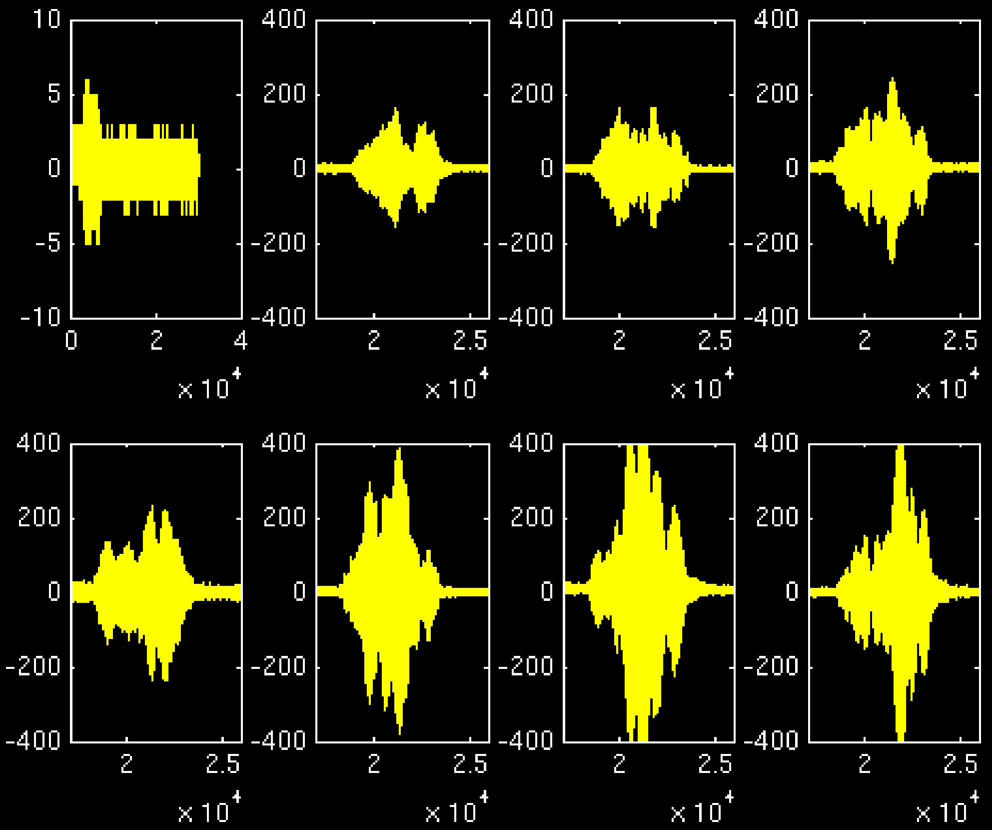
# Ping series from a swimming fish

# Ping series from a rotating fish

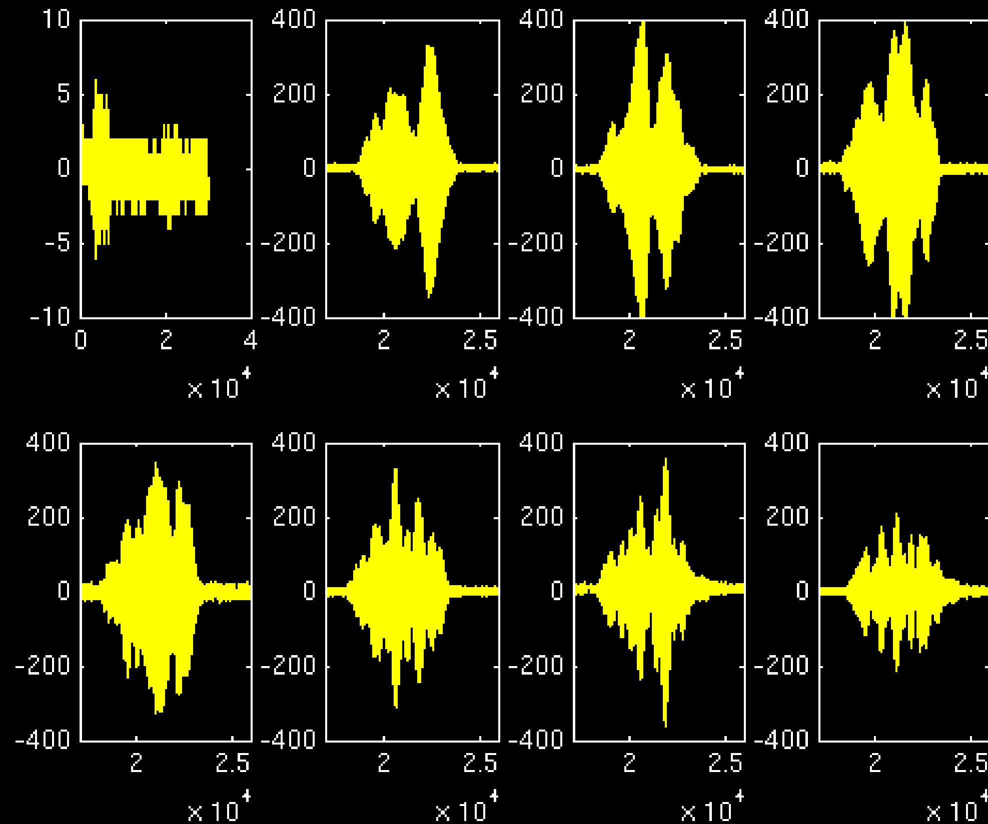
# Ping frames from swimming fish



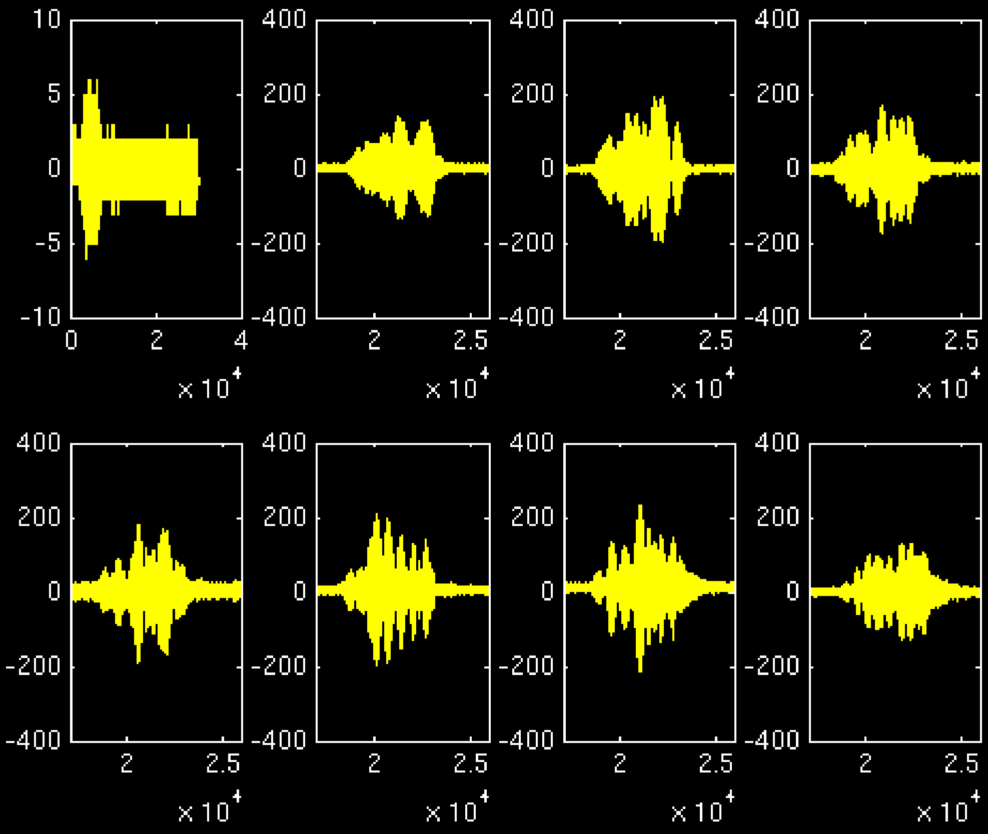
# Ping series from swiming fish



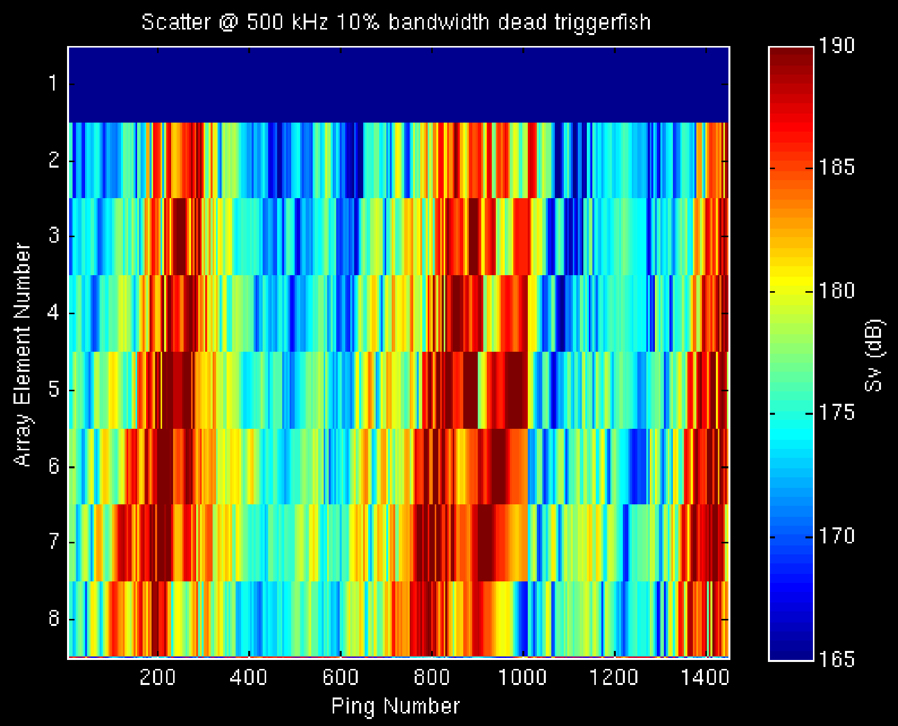
# Ping series from swimming fish

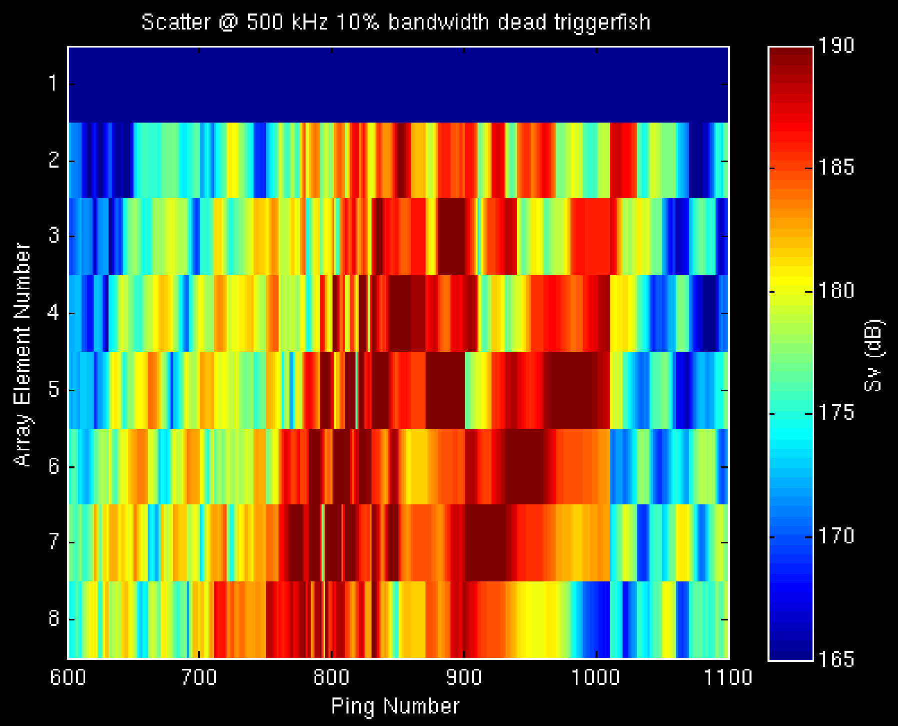


# Ping series from swimming fish

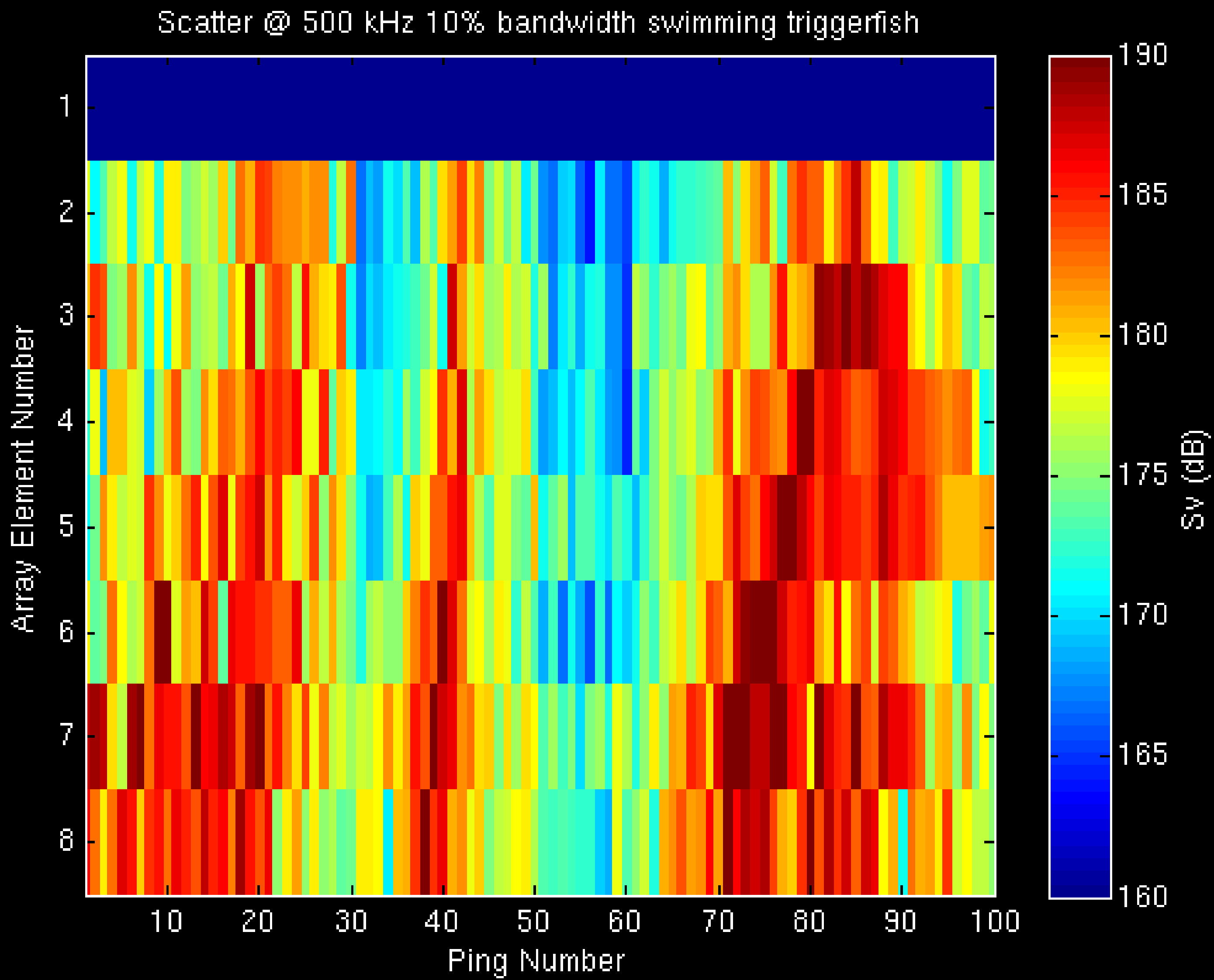


# Ping series of per frequency energy



# Ping series of per frequency energy (swimming fish)



# Looking towards the future

- What kind of algorithms are appropriate?
- How can the system perform well without excessive training?
- What type of features are uniformly best for representing these data.
- What are the limitations on discrimination capability.

# Summary

- A multiple angle scattering apparatus has been constructed and tested.
- Improved image calibration is needed for pose estimation.
- Preliminary data shows important advantages of using additional angles.
- Future algorithm development should aim to use time varying scatter, regional data for priors, and multiple classification paradigms.

# Acknowledgments

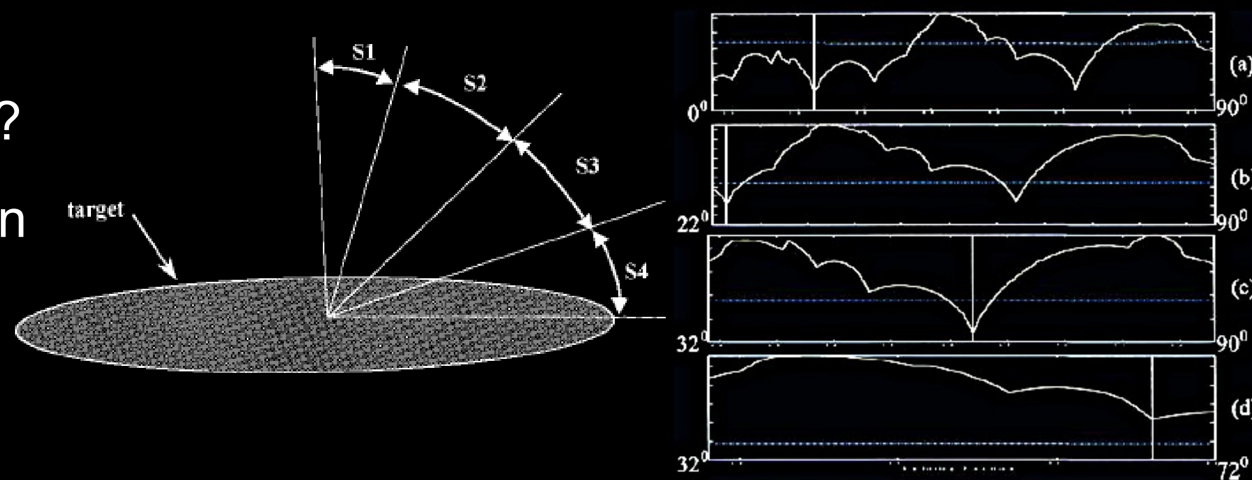

- Funding from California Sea Grant
- Contributions from Jules S. Jaffe, Fernando Simonet, Erdem Karakoylu, Ben Maurer, Rob Glatts, Eddie Kisfaludy, HJ Walker, and the SIO machine shop.


# Previous appraoches to the problem

- Sequential state estimation
  - Robinson, Dasgupta, Runkle, Carin.
- Neural networks, support vector machines, nearest neighbor
  - Azimi-Sadjadi, Yu, Roberts.

# State estimation methods

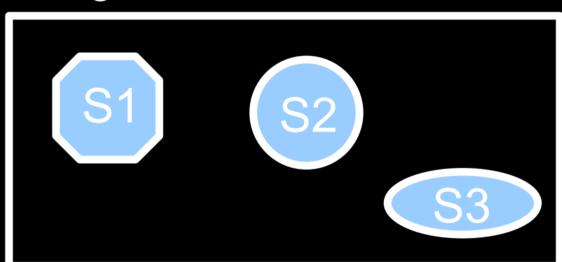
- What should the state be?
- How to estimate emmision probabilities?
- How to model state transitions?



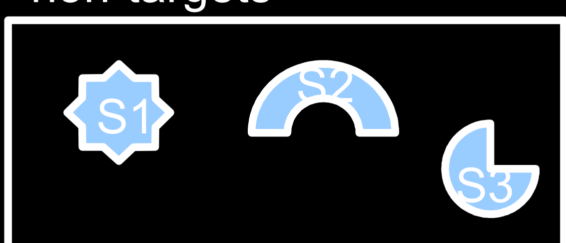

Physics based state decomposition

$$p(y_n|s_m,T_k) = \sum_{l=1}^{L} w_l g_l(y_n|s_m,T_k), \qquad \sum_{l=1}^{L} w_l = 1.$$

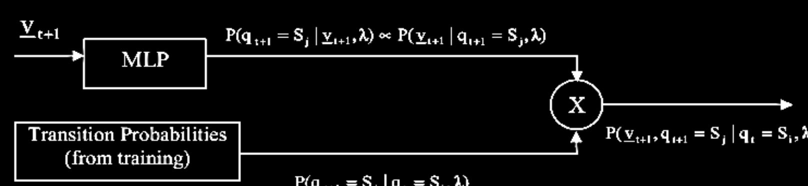
targets




non-targets

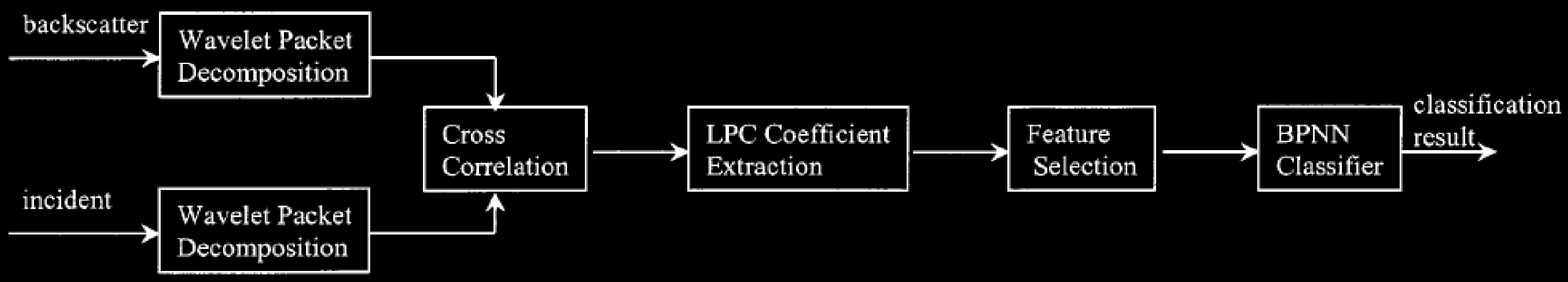



Object based decomposition




Block diagram of the HMM/MLP system for local probabilities.

# Non-parametric methods




Data Pre-processing and filtering

Feature extraction

Pick best features

Classify using training data.

# Limitations of current methods

- Only process spatial data, either from simultaneous views of a dynamic target, or for sequential views of a static target.
- Heavy dependence on training data, which is expensive to obtain.
- Unclear how these methods will generalize to new target types.

# Improving existing methods