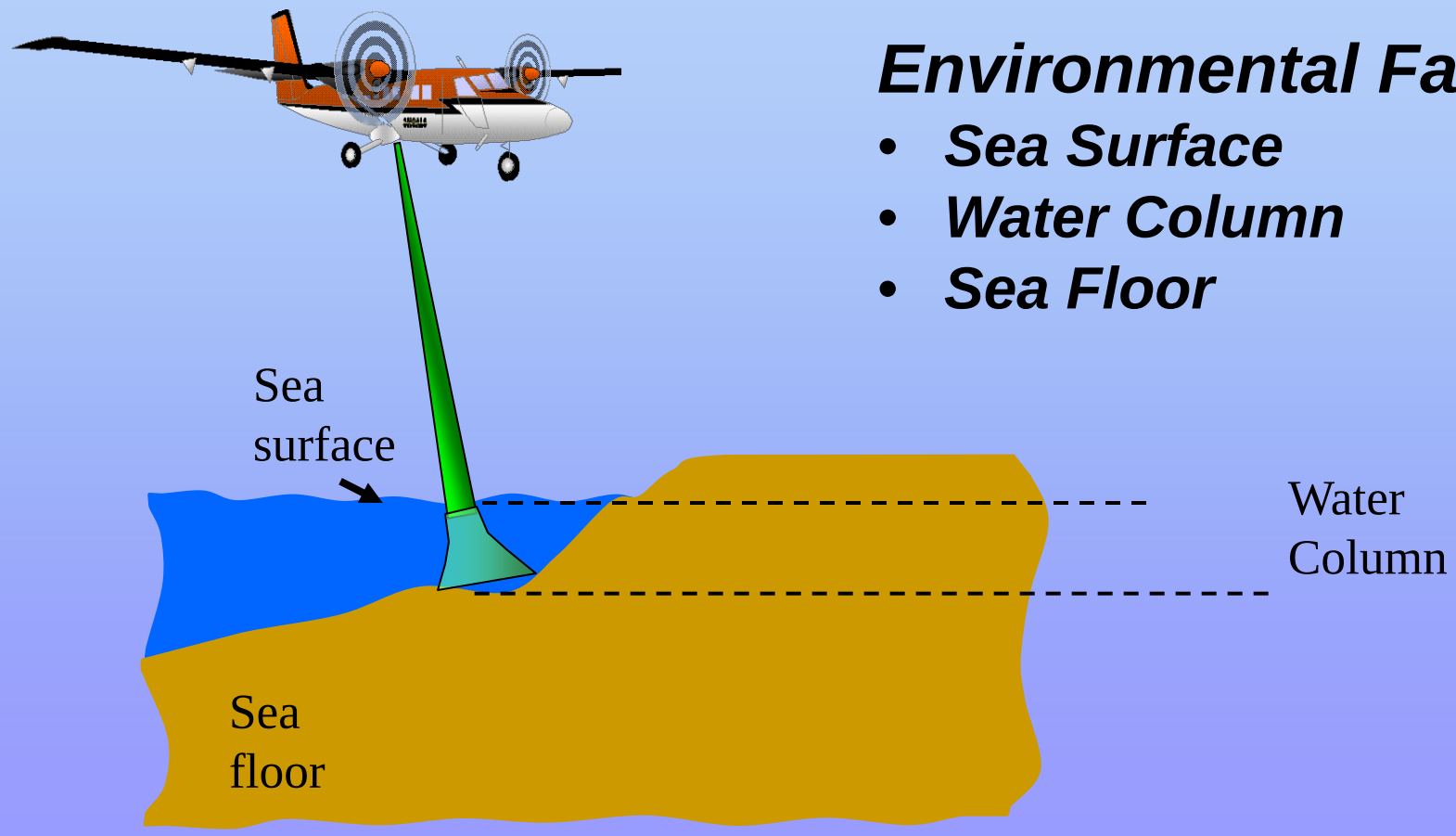
Underwater-Detector Array for Laser Beam Diagnostics

Matthew Birkebak, Firat Eren, Shachak Pe'eri, Yuri Rzhanov

Center for Coastal and Ocean Mapping/Joint Hydrographic Center

Environment



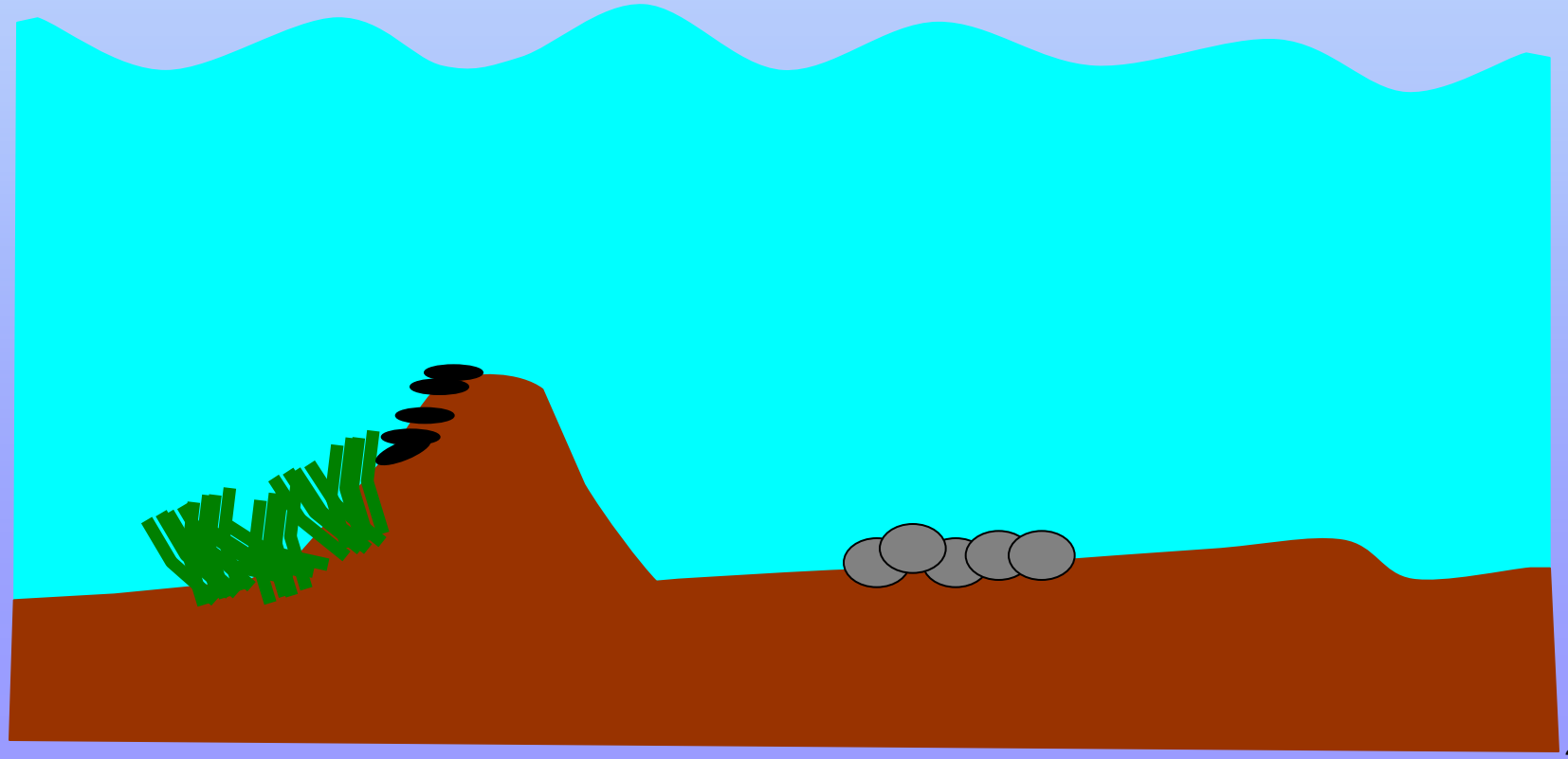
Environmental Factors

- ***Sea Surface***
- ***Water Column***
- ***Sea Floor***

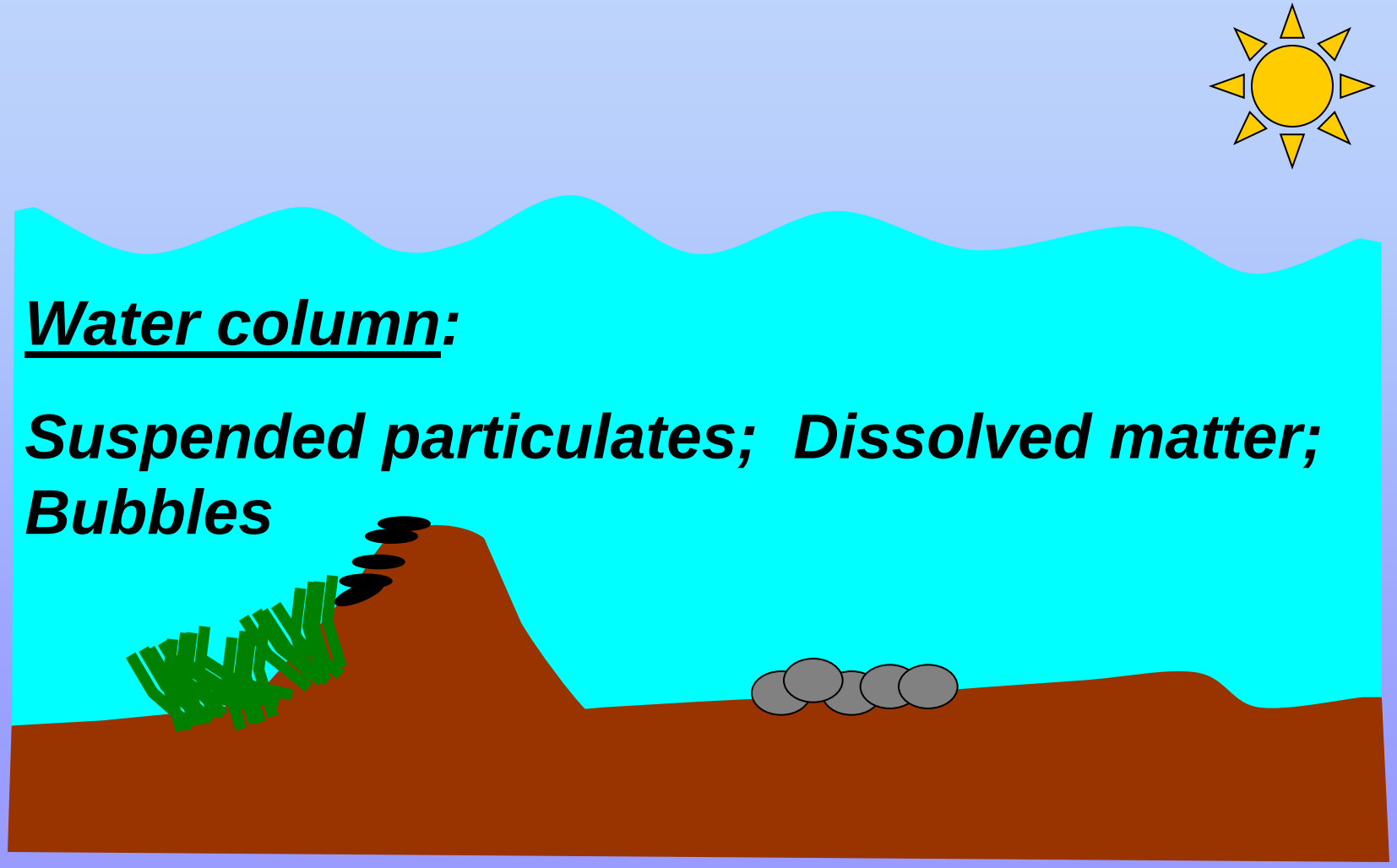
Environment

Water surface:

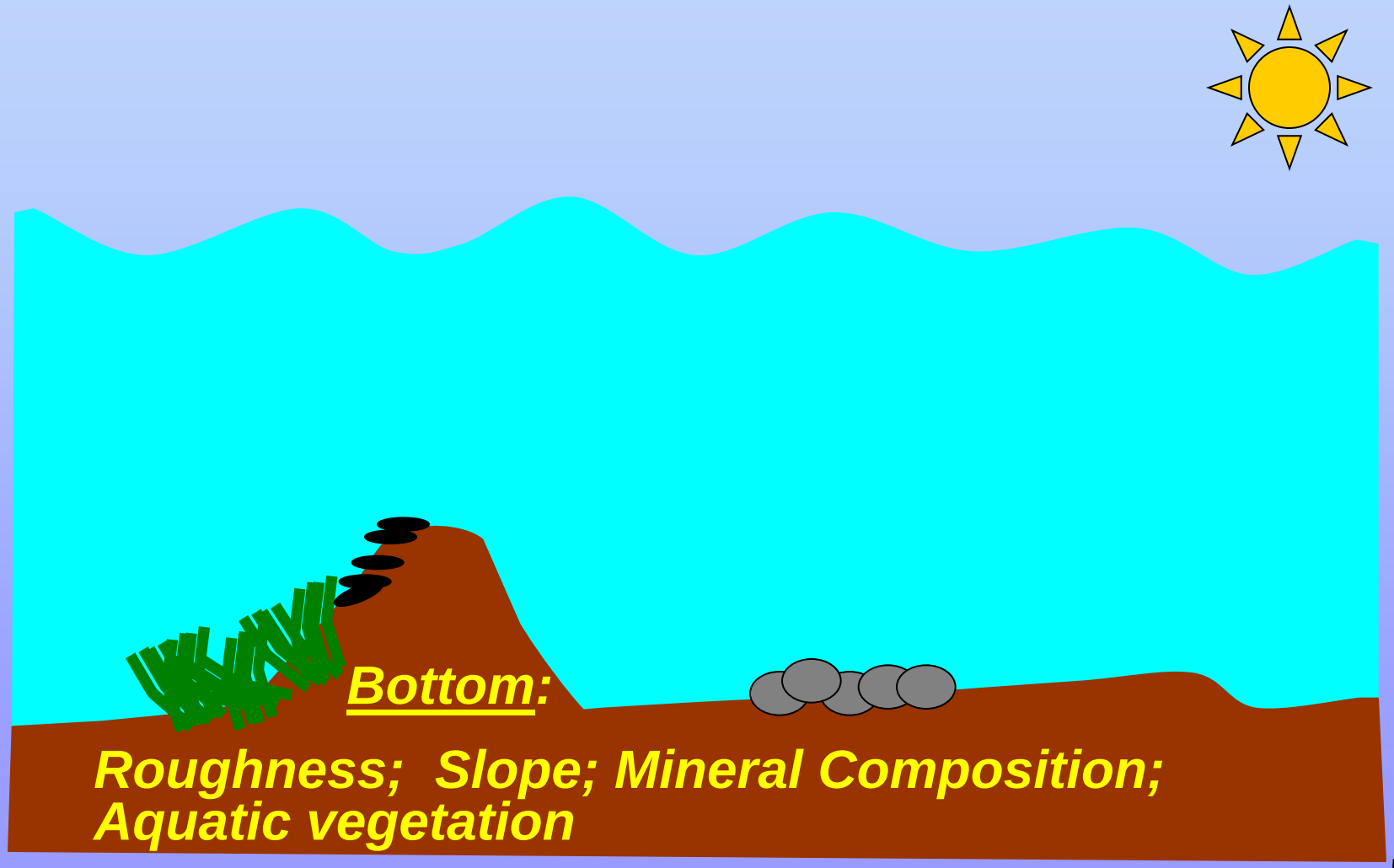
Sun glint; Morphology; White caps



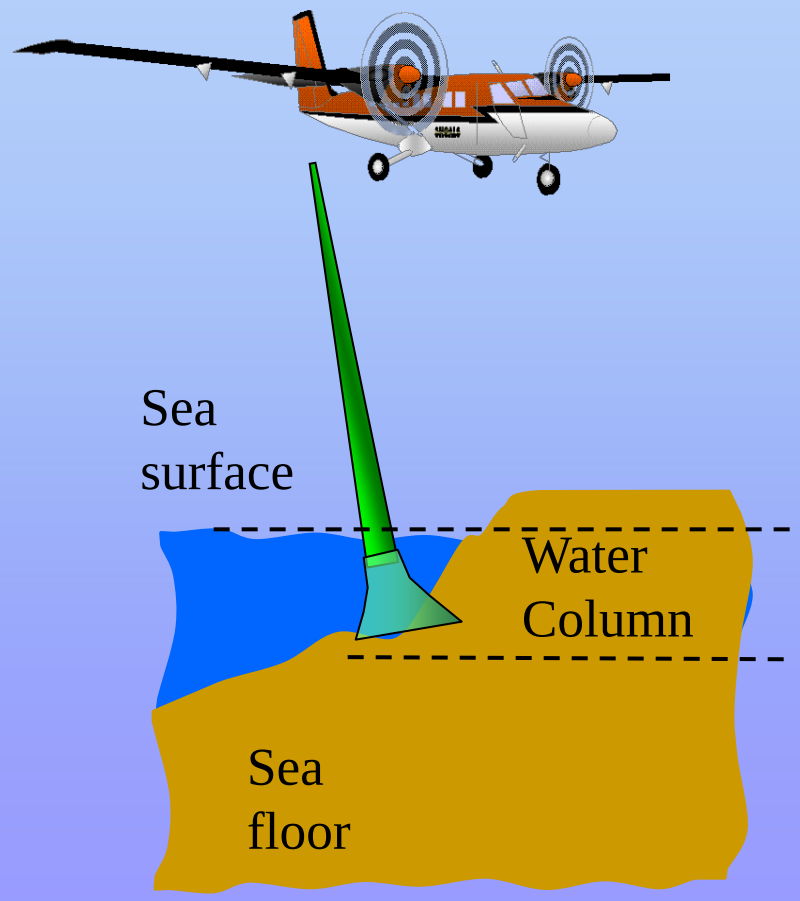
Environment



Environment



Research Goals



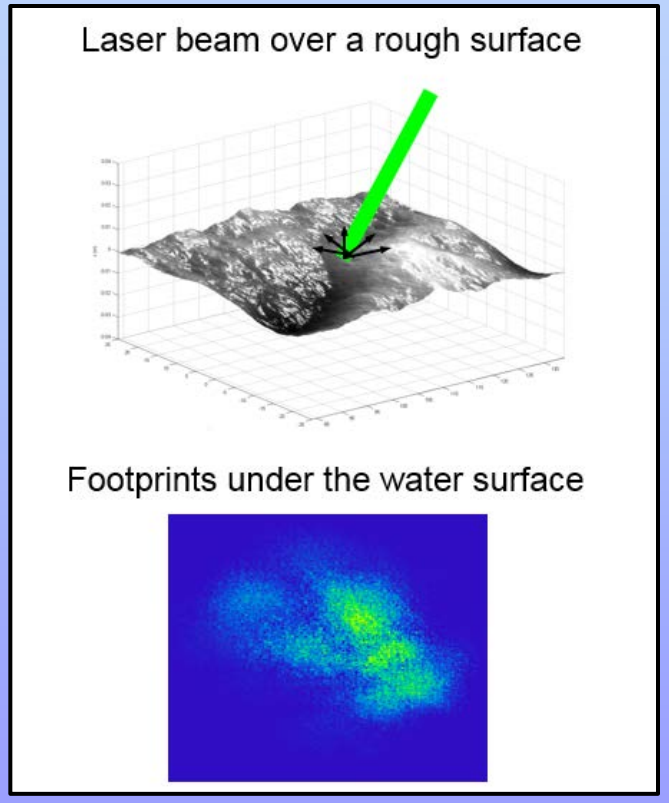
Goal:

- Design a detector array for beam diagnostics.
- Calibrate array for visualization of beam.
- Conduct experiments to quantify environmental effects.

Previous Work

Simulation work (water surface):

- Capture refracted footprints.
- Calculate average position of the intensity profiles.
- Predict position distribution based on water surface condition.



T. Karlsson, Pe'eri, S., and Axelsson, A., “The Impact of Sea State Condition on Airborne Lidar Bathymetry Measurements”, SPIE Defense, Security and Sensing (Laser Radar Technology and Applications XVII). Baltimore, MD, 2012.

S. Pe'eri, Karlsson, T., Axelsson, A., Rzhanov, Y., and Riley, J., “The Sea State Condition as an Environmental Factor in Airborne Lidar Bathymetry (ALB)”, 13th Annual Coastal Mapping & Charting Workshop of the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX). Chicago, IL, 2012.

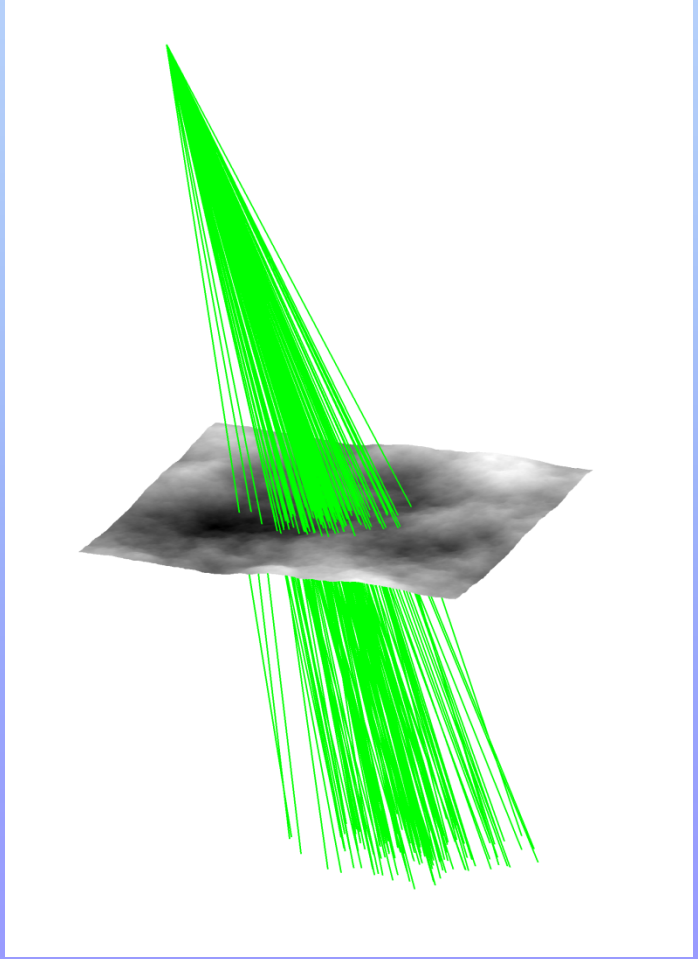
Study Approach

Simulations:

- Construct a realistic ocean surface
- Perform ray-tracing
- Statistical analysis

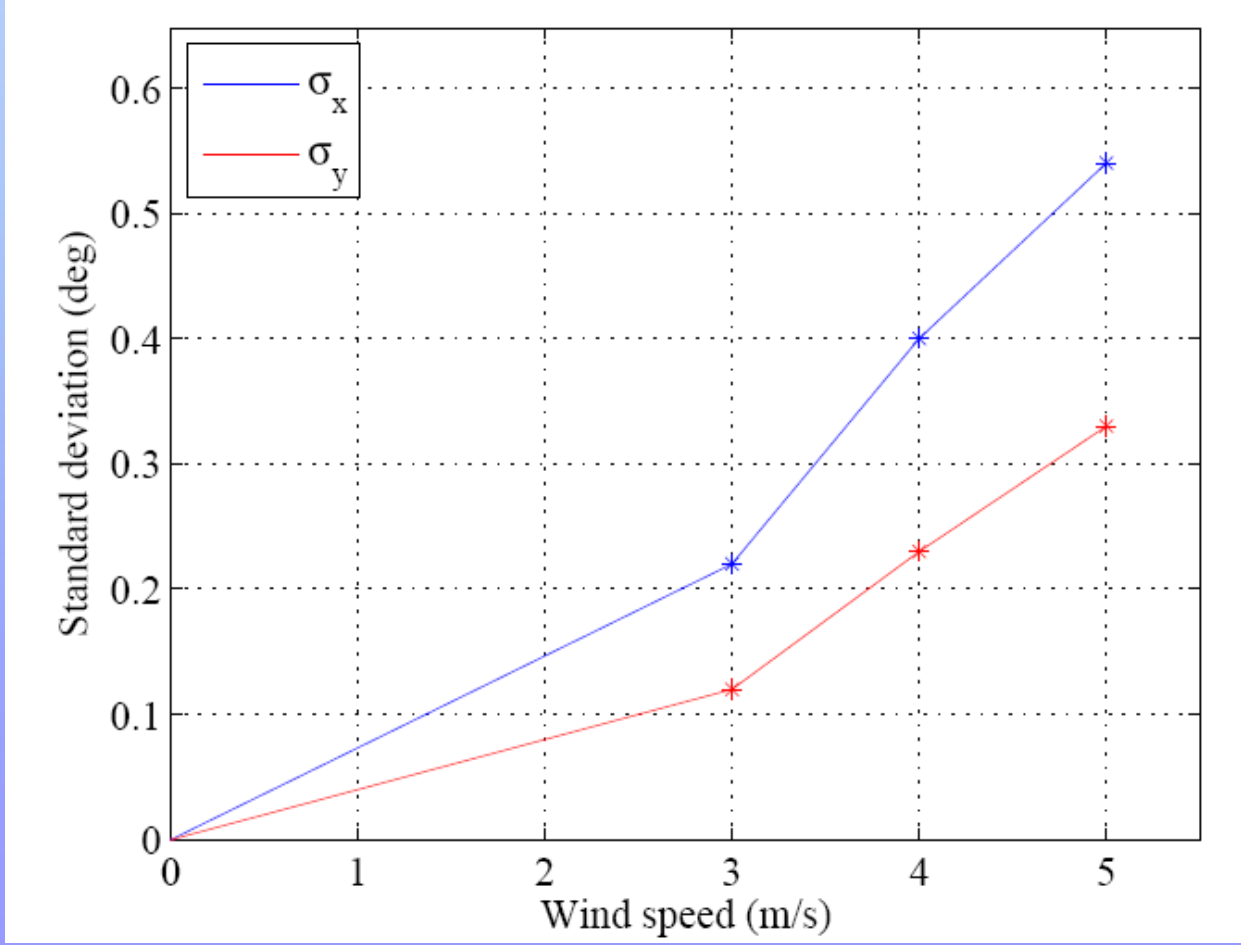
Experiments:

- Validate the simulations.



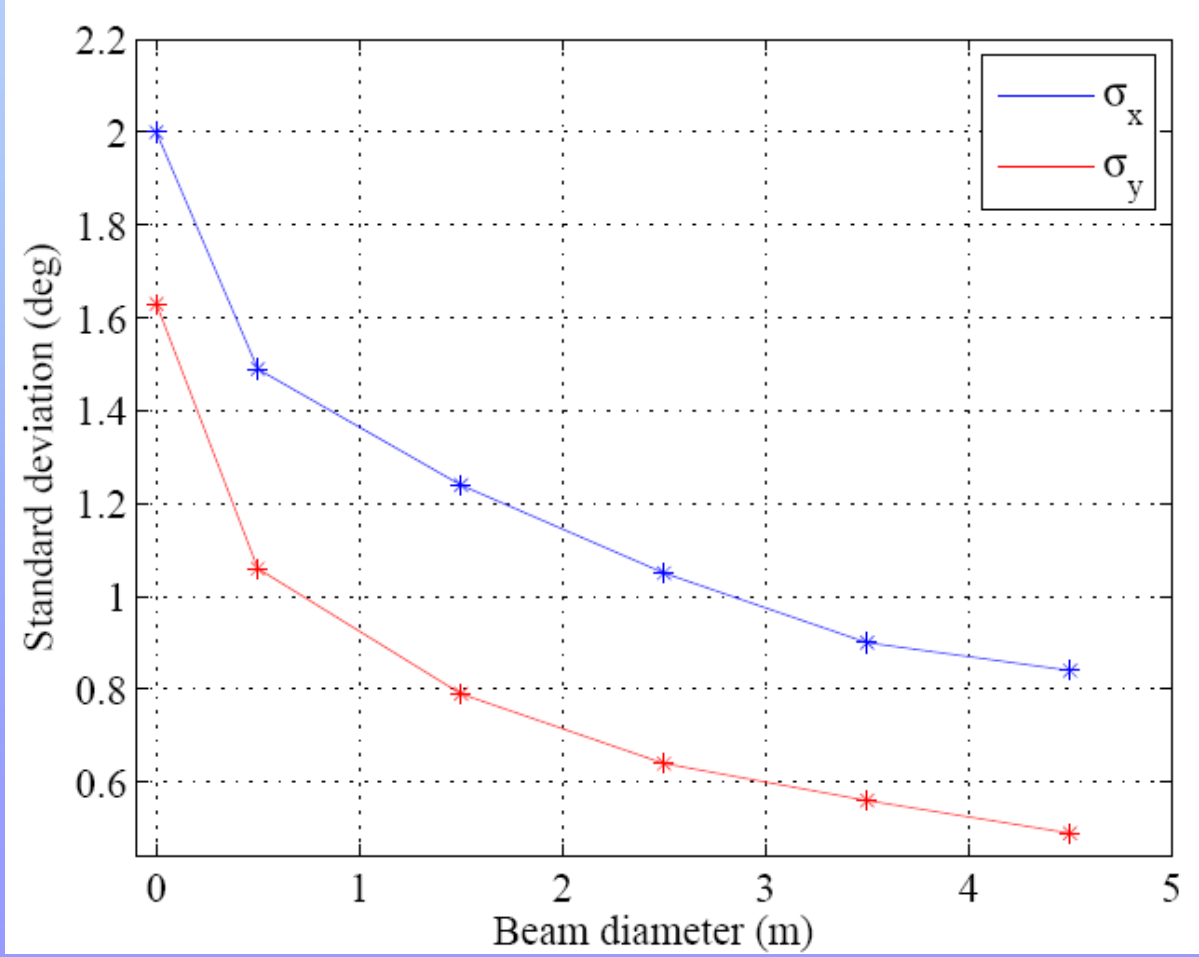
Results: Wind speed

Fetch length: 35 km Beam diameter: 4.5 m

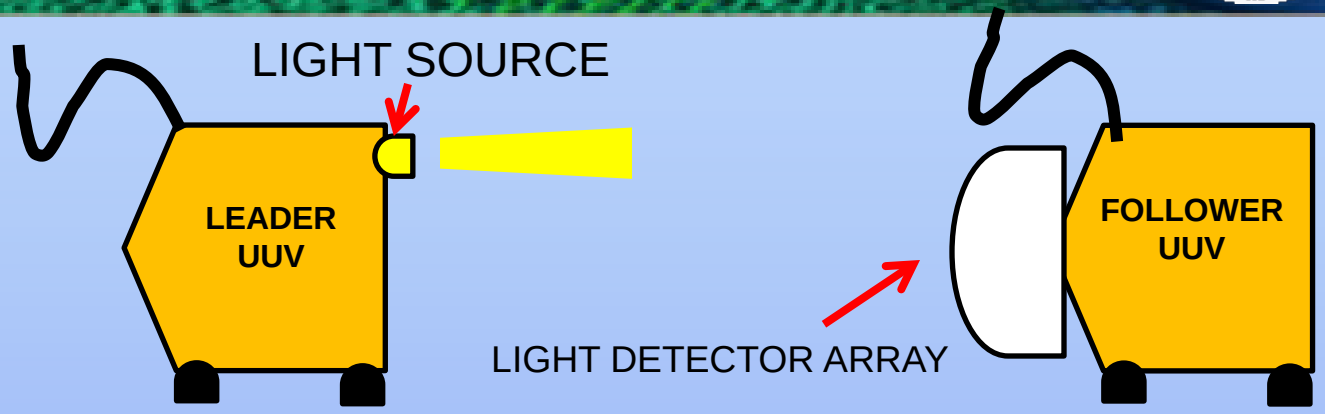


Results: Beam diameter

Wind speed: 5.4 m/s Fully developed ocean



Previous work



1) Detector Array

F. Eren, S. Pe'eri, Y. Rzhanov, M. Thein and B. Celikkol, "Optical Detector Array Design for Optical Sensor Based Pose Detection between Unmanned Underwater Vehicles (UUVs)," 2015. (*IEEE Journal of Oceanic Engineering* – DOI - 10.1109/JOE.2015.2389592)

2) Pose Detection and Control Algorithms

F. Eren, M. Thein, S. Pe'eri, Y. Rzhanov and B. Celikkol, "Development of pose detection algorithms for dynamic positioning of unmanned underwater vehicles (UUVs) utilizing optical feedback," (*IEEE Journal of Oceanic Engineering* – under review)

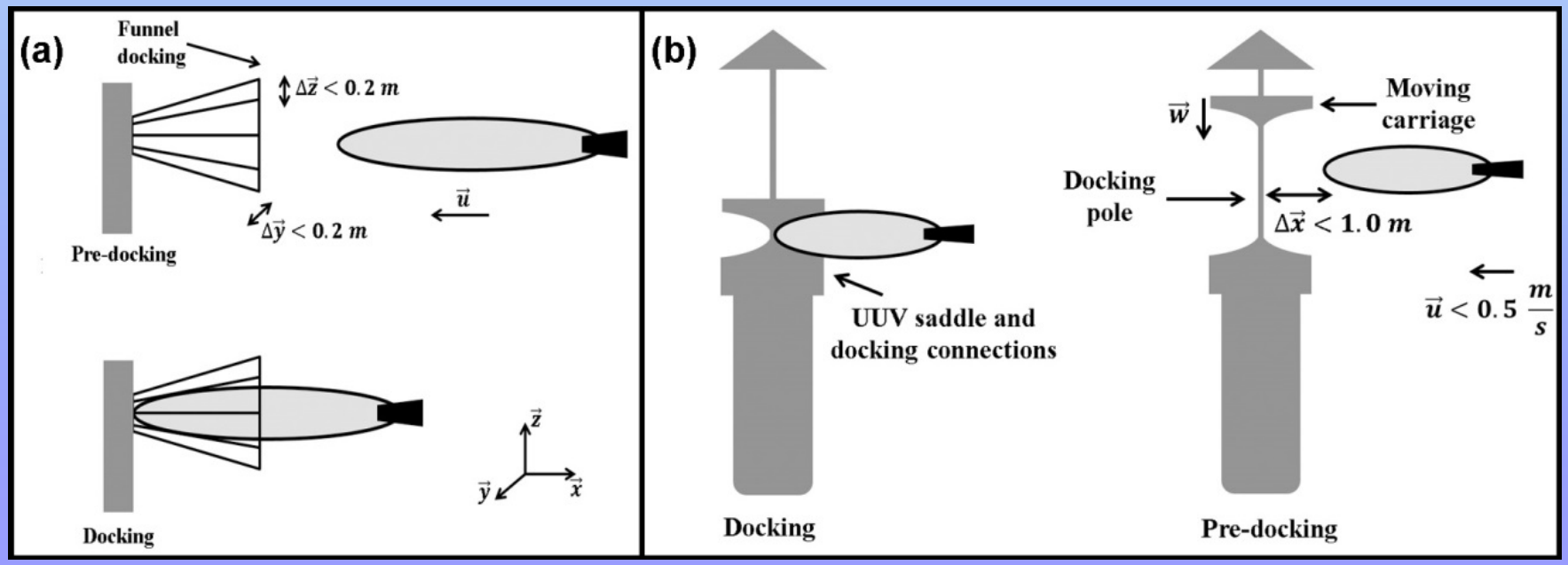
3) Performance Evaluation

F. Eren, S. Pe'eri, Y. Rzhanov, M. Thein, B. Celikkol and R. Swift "An Experimental Study for feedback and control system using an optical detector array for pose detection of UUVs" (*Applied Optics*–submitted in June, 2015)

Docking systems

Pose detection

Navigation into a docking station

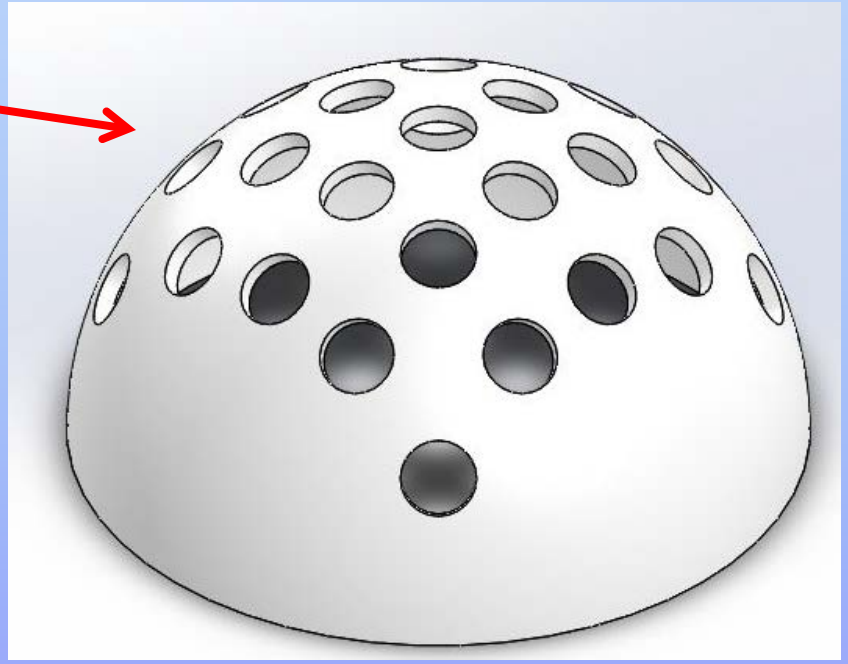


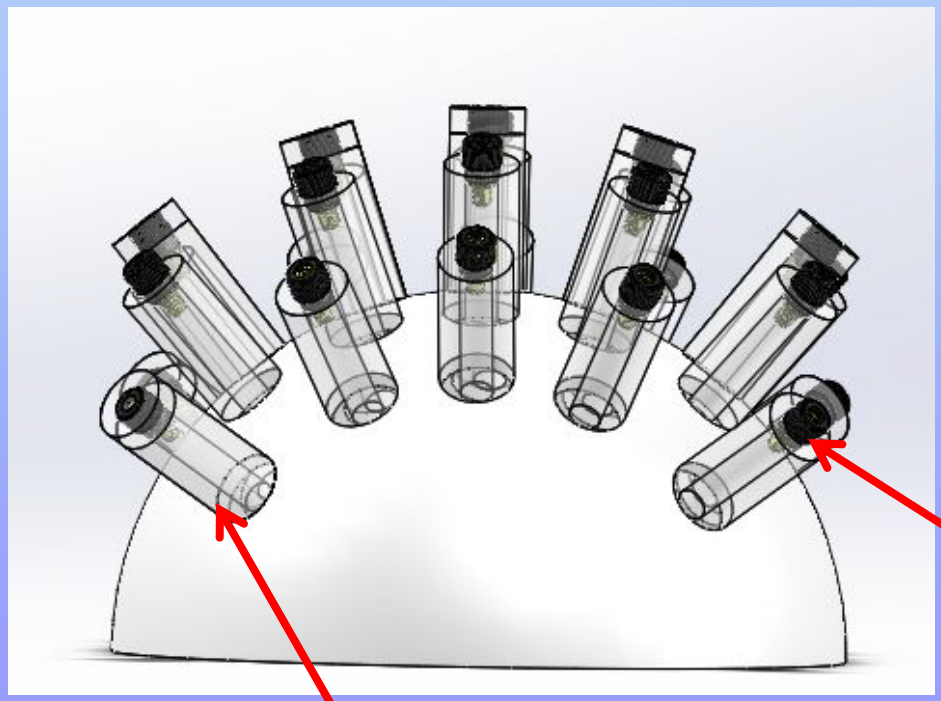
Vehicle entrance trajectory

Vehicle speed

Spherical Detector Array

3D printed ABS dome (10 inch diameter)





Photodiode

Housing fixture for photodiodes

Key Image Parameters

Comparison based on image properties

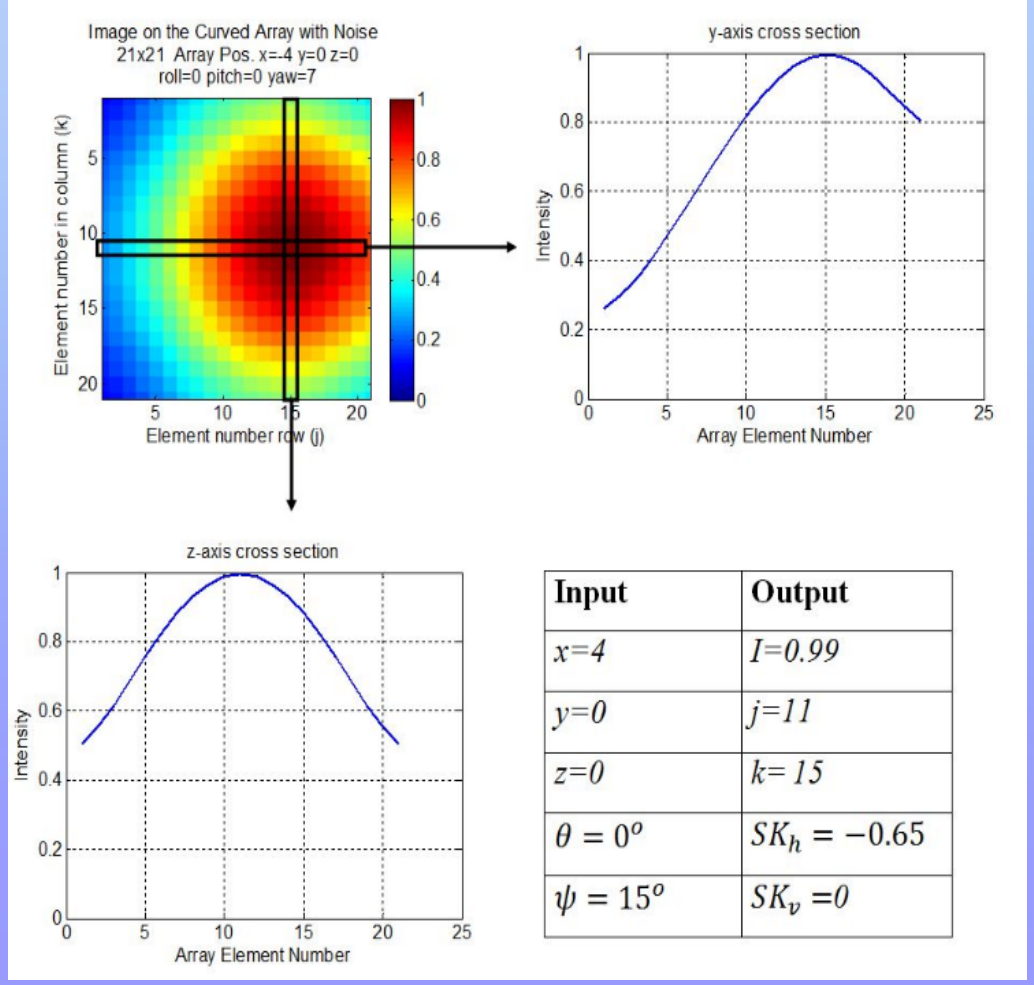
Skewness of the gradients

- o Along row profile, Sk_x
- o Along column profile, Sk_y

Spectral Angle Mapper (SAM)

$$\alpha = \cos^{-1}\left(\frac{\overrightarrow{U_t}\cdot\overrightarrow{V_t}}{\|\overrightarrow{U_t}\|\cdot\|\overrightarrow{V_t}\|}\right)$$

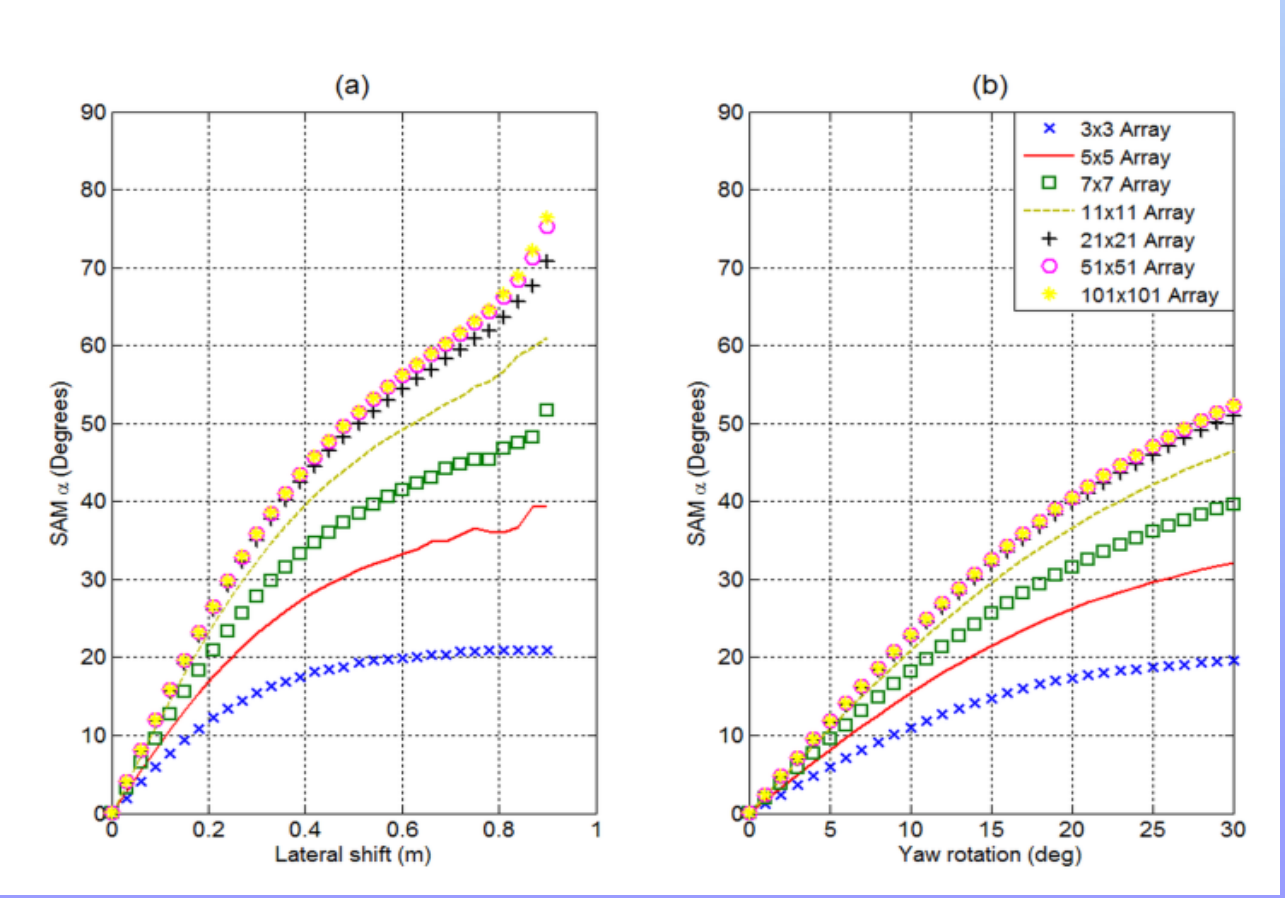
U_t = Reference image
V_t = Image Under Test
α = SAM angle



Input	Output
$x=4$	$I=0.99$
$y=0$	$j=11$
$z=0$	$k=15$
$\theta = 0^o$	$SK_h = -0.65$
$\psi = 15^o$	$SK_v = 0$

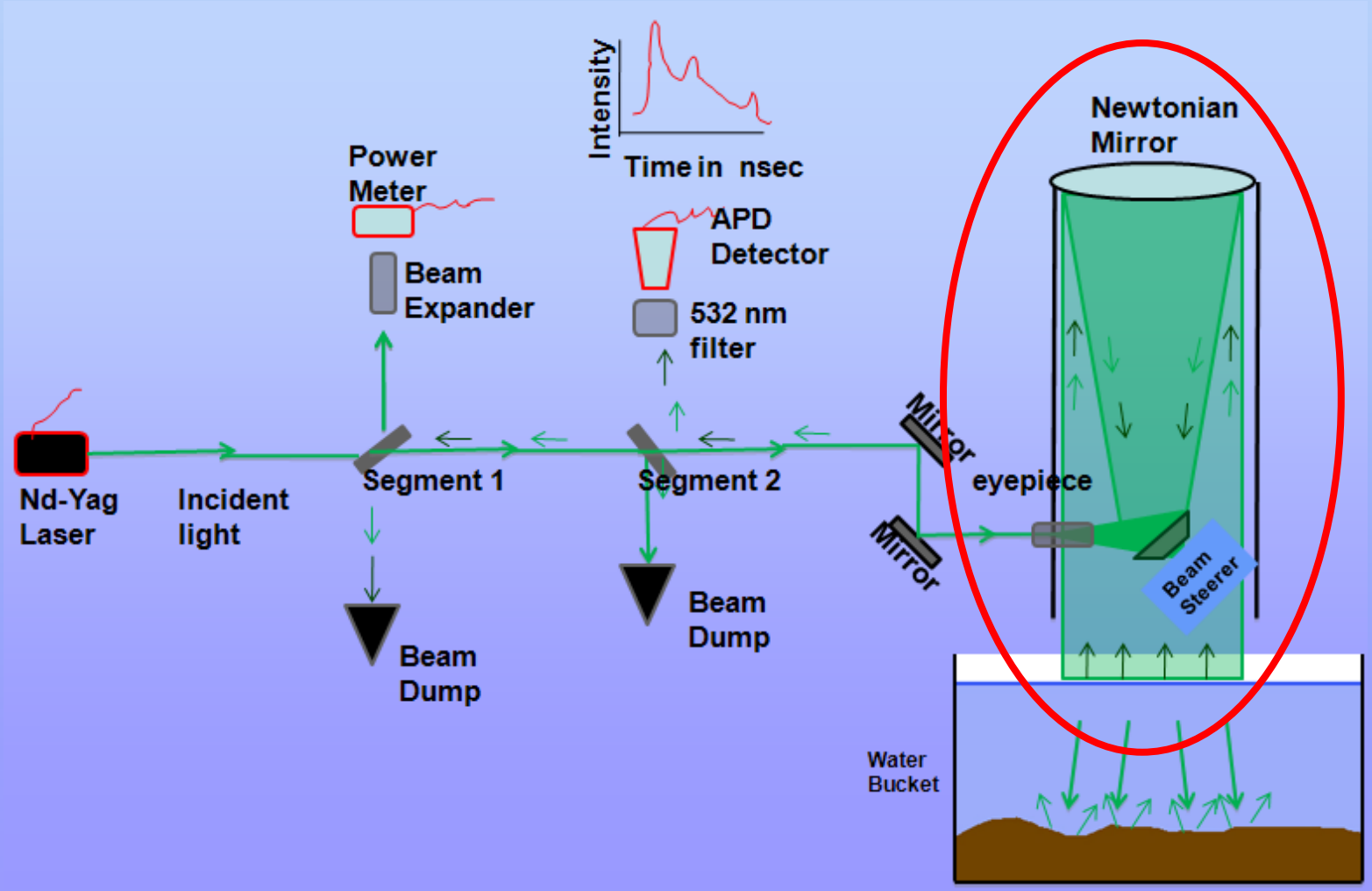
Curved Array Comparison

Varying Array Size



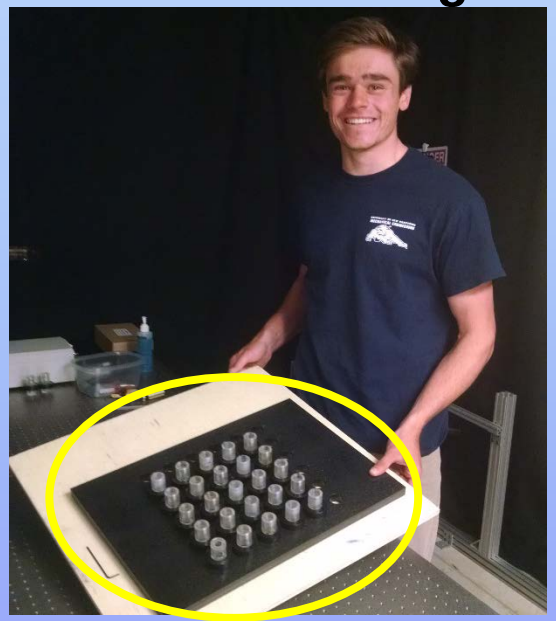
15 degrees SAM angle → 0.2 m translation, 10° yaw

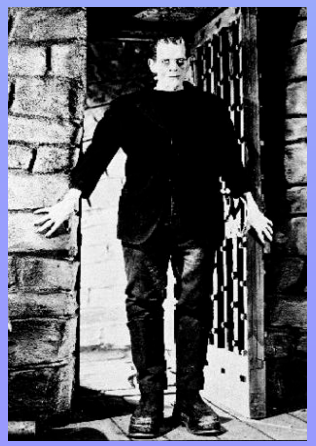
LiDAR Simulator



Planar Detector Array

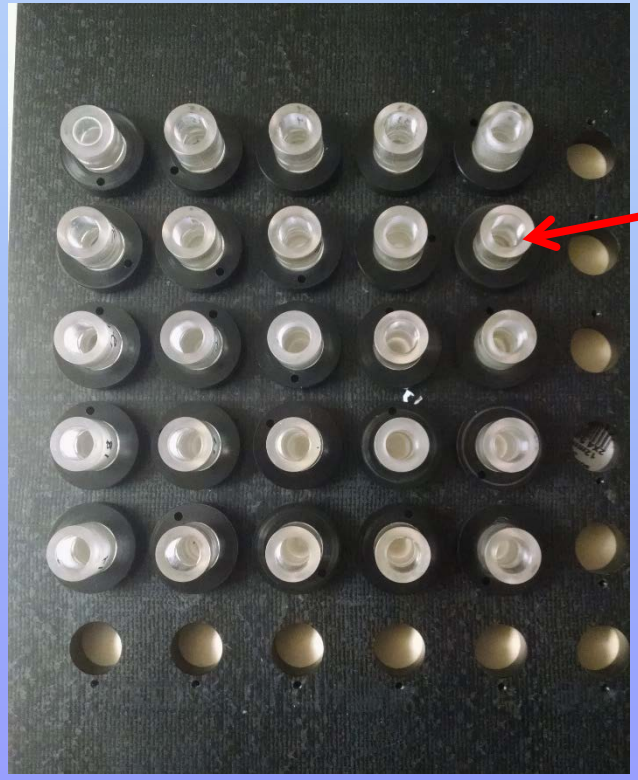
Planar Design





From bulky and awkward to a compact detection unit

Planar Detector Array



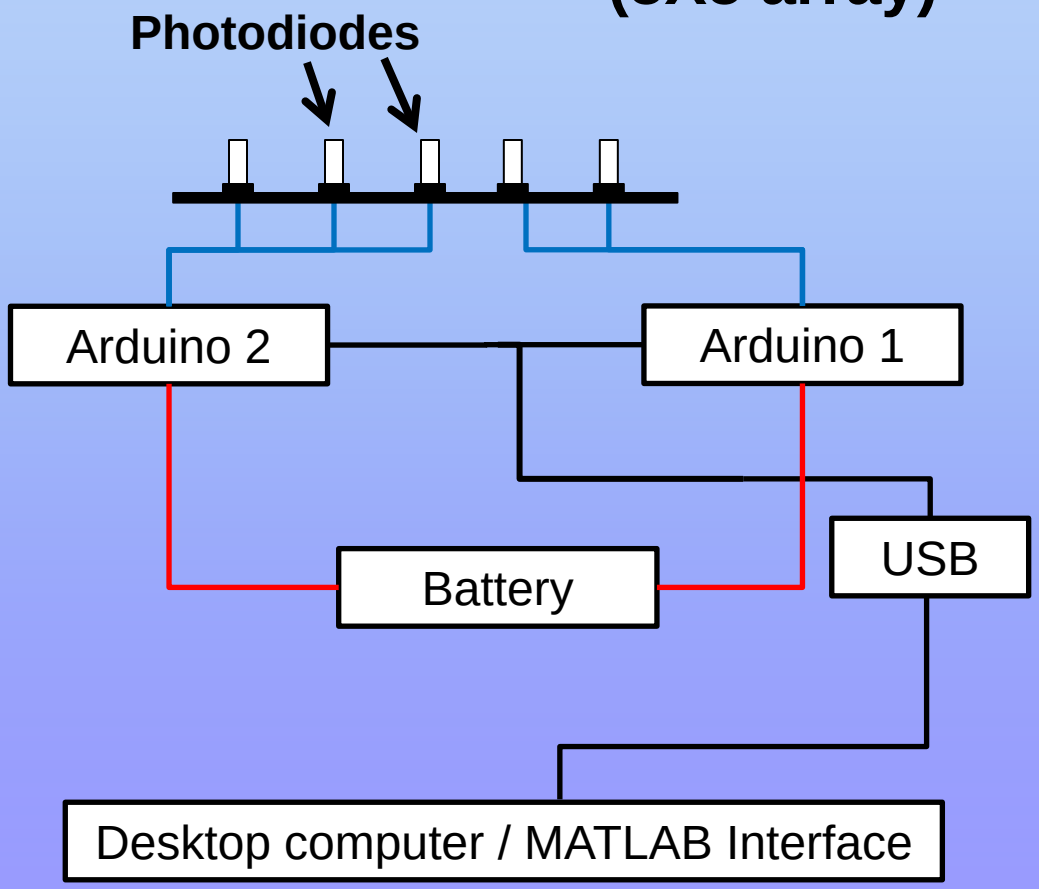
Acrylic fixtures

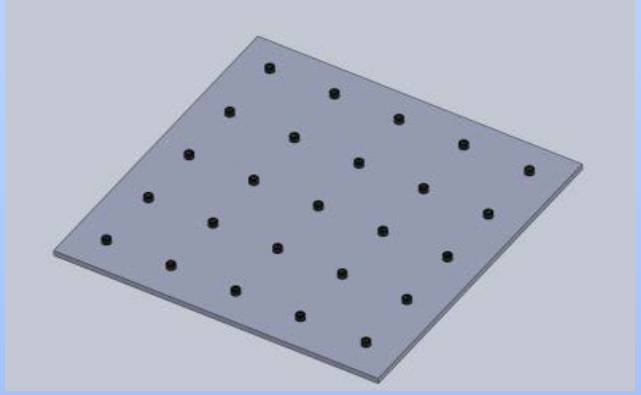
5X5 setup

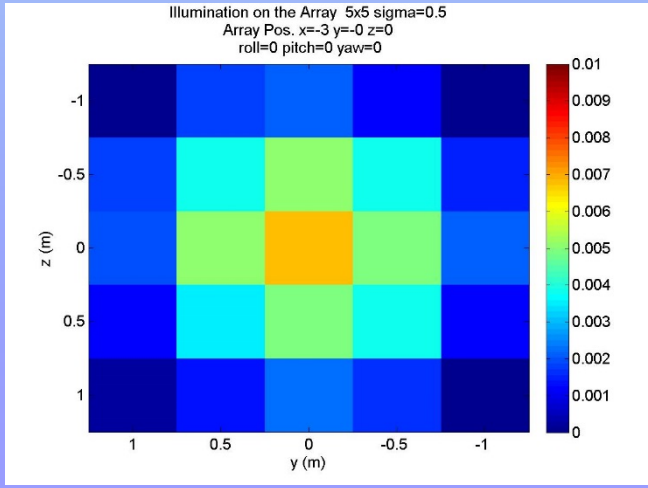
6X6 setup

Detector Array Concept

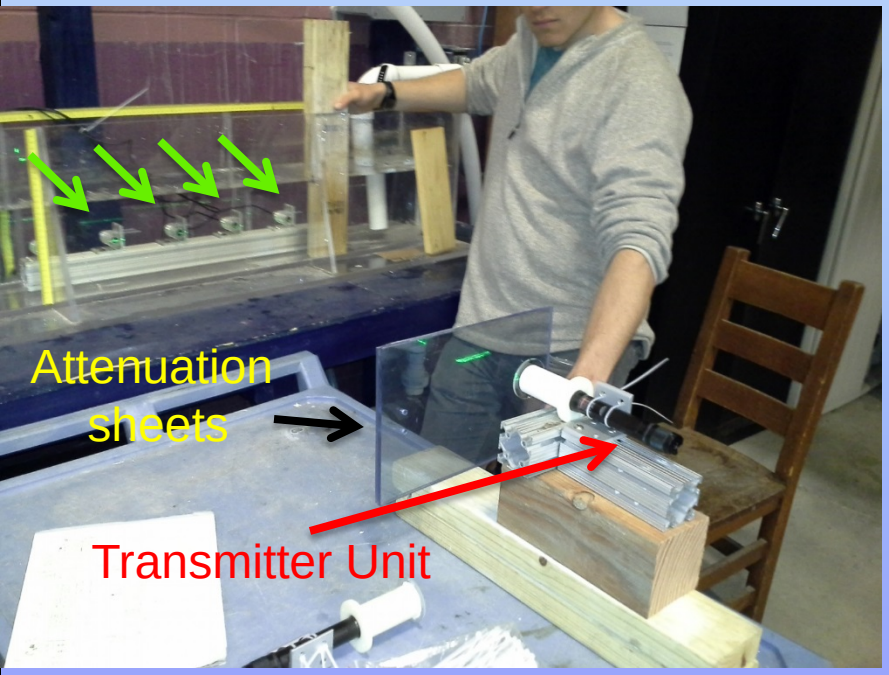
OPTICAL MODULE (5X5 array)

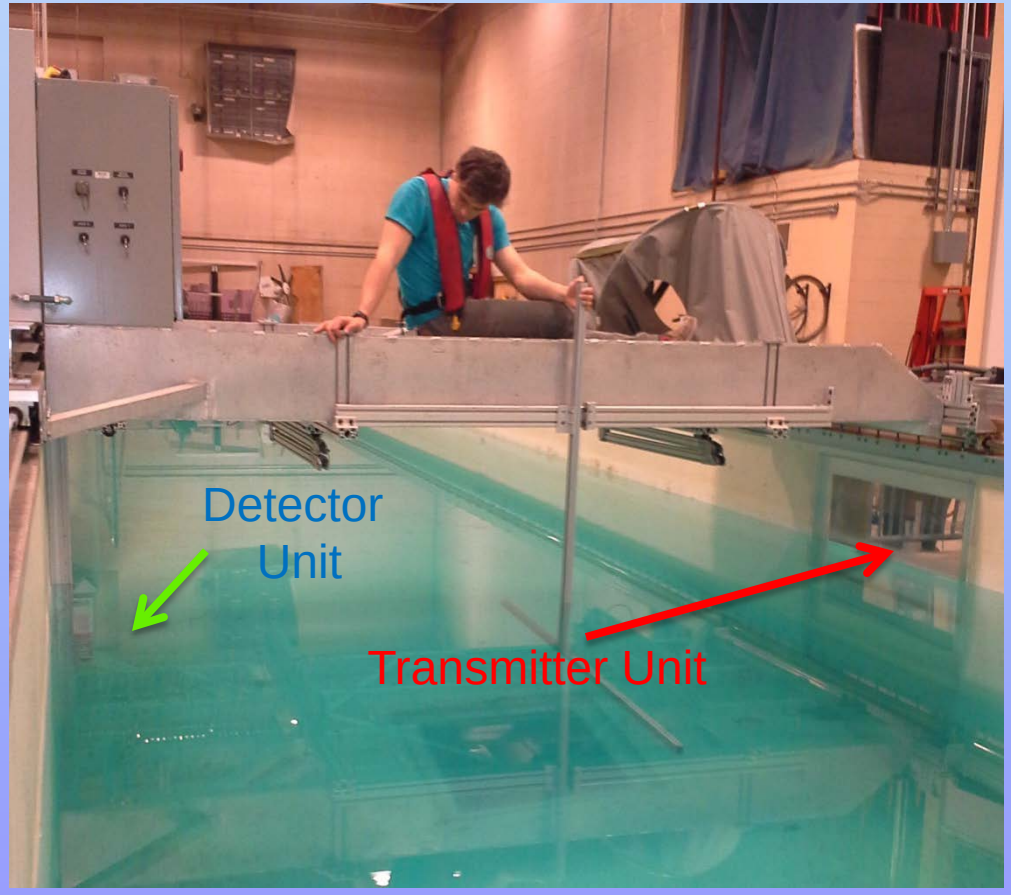






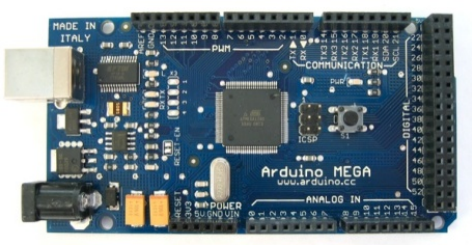
Undergraduate Research





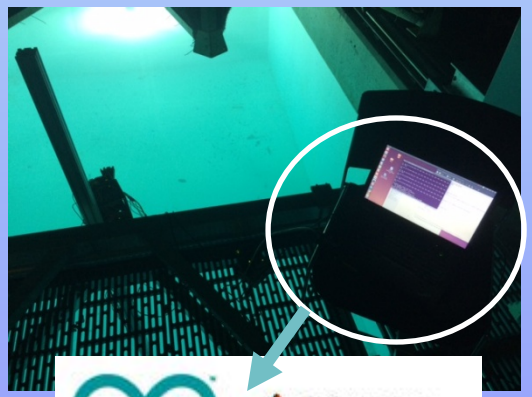
Components

Photodiode



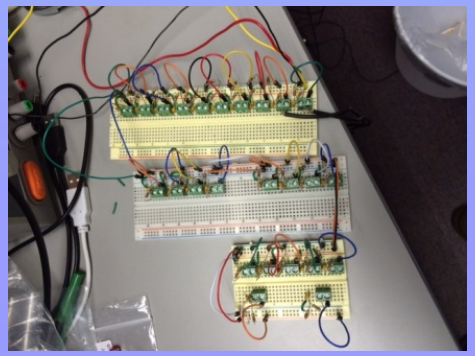
Arduino

10 ft. SMA cables



PC and data-log

Reverse-bias circuit



MATLAB Arduino support package

Calibration Procedures

- **Photodiode calibration**

  Output consistency for all 25 photodiodes

- **Temperature sensitivity**

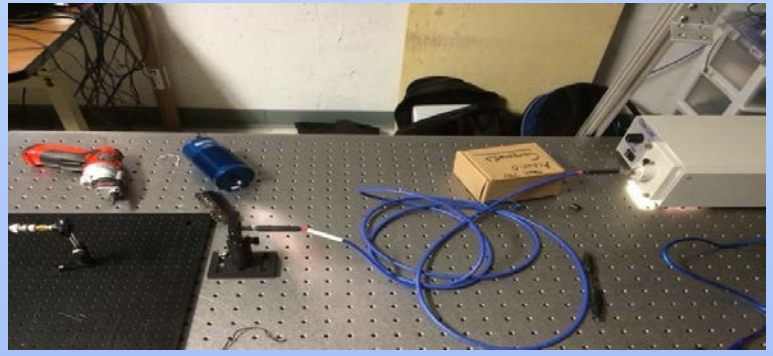
  Explore the change in quantum efficiency of each photodiode w.r.t medium temperature

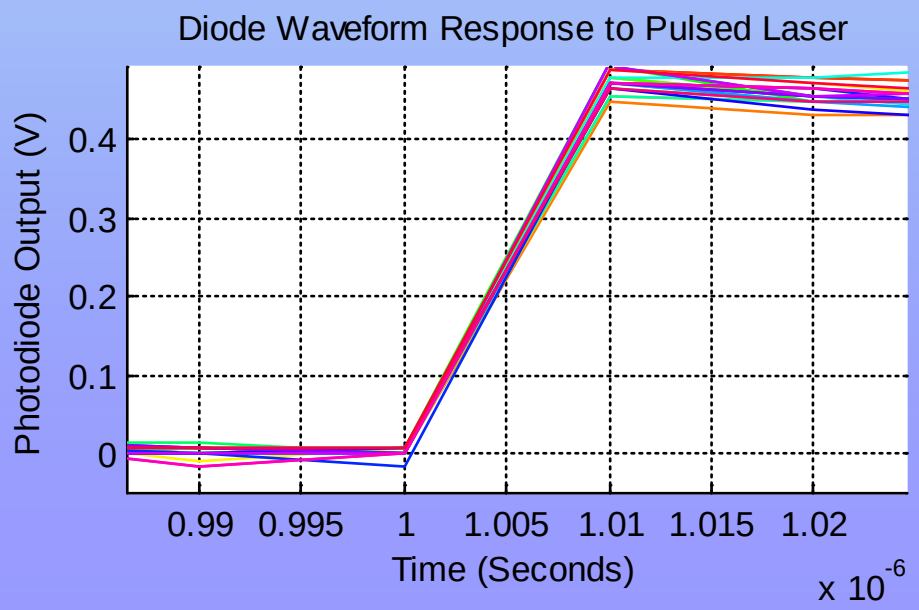
- **Pose calibration**

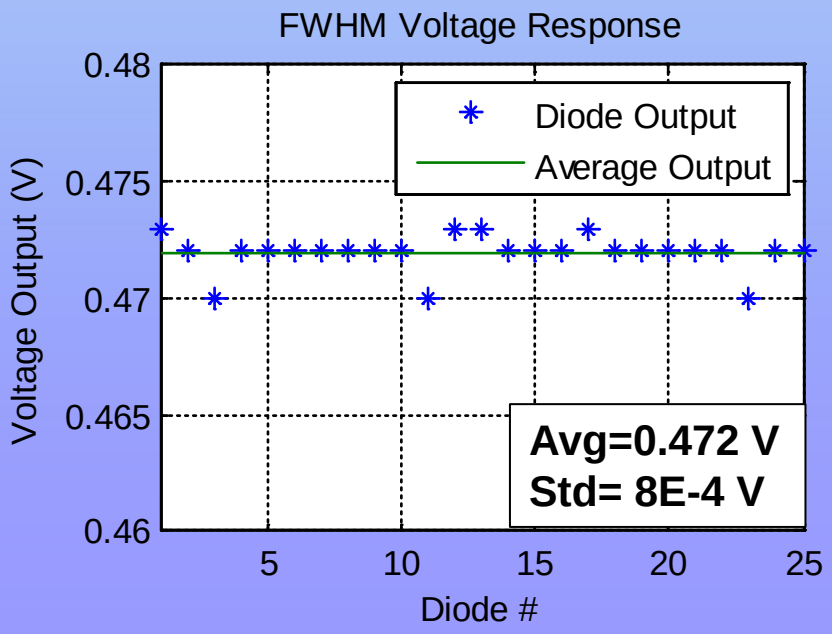
  Determine the pose based on sampled beam pattern

Photodiode Calibration

Photodiode

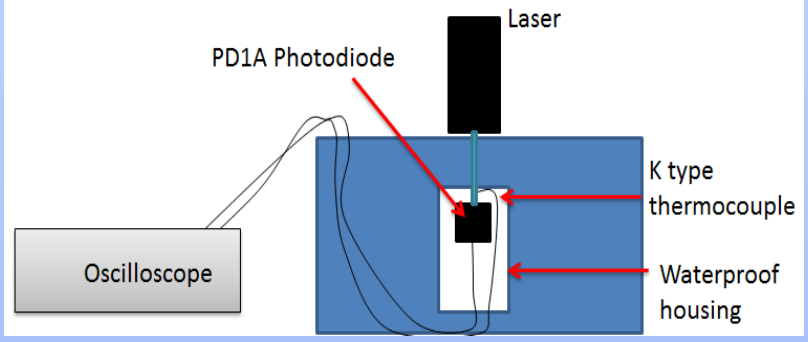






Temperature Sensitivity

Temperature varied from 20 °C to 60 °C at 10 °C increments

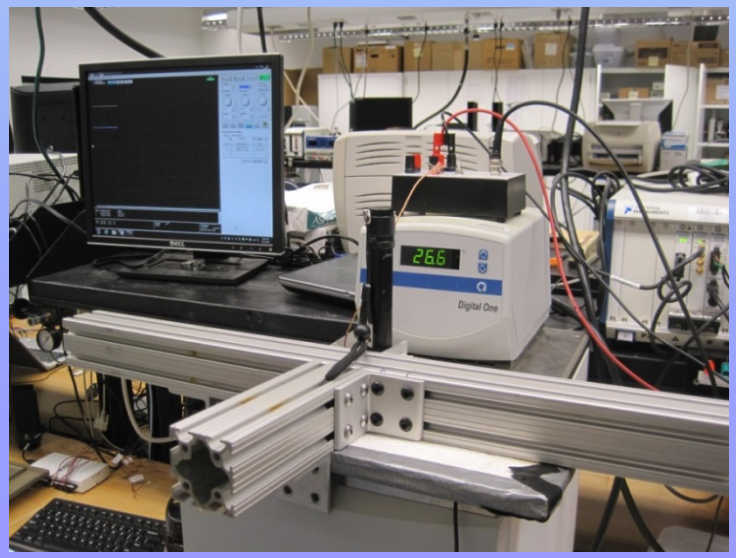


Experimental Setup

T ⇧ V ⇩

Based on a linear fit:

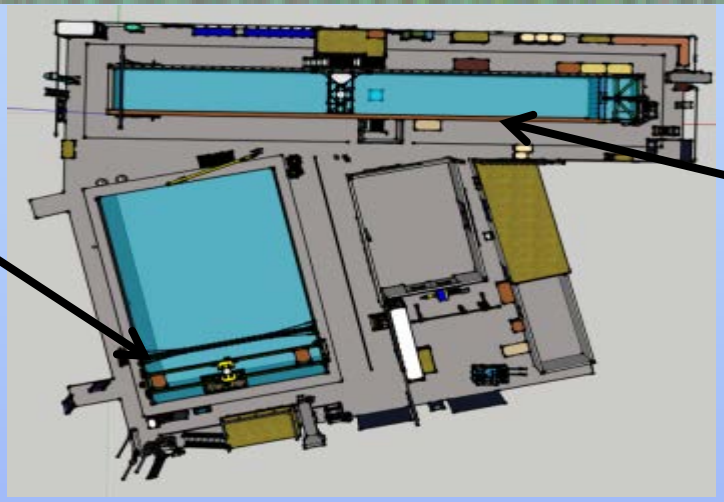
$$Vo(T) = -2 * T + 576$$



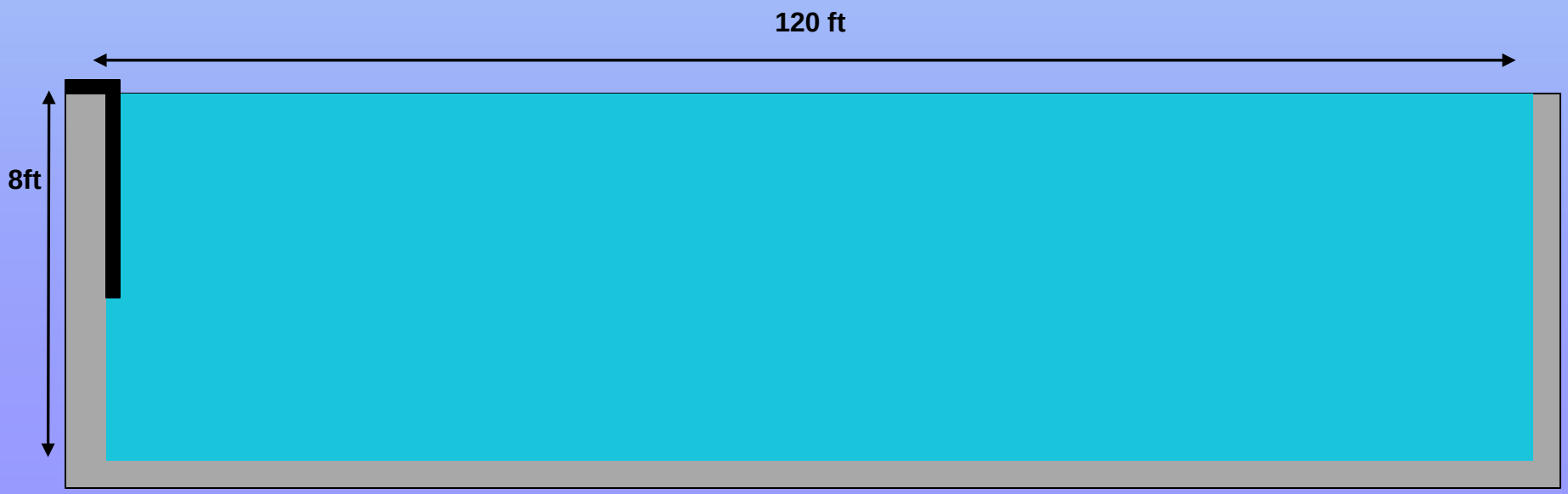
UNH Mechanical Eng. Laboratory

UNH Water Tank Facilities

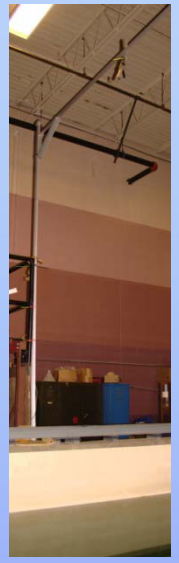
Engineering tank

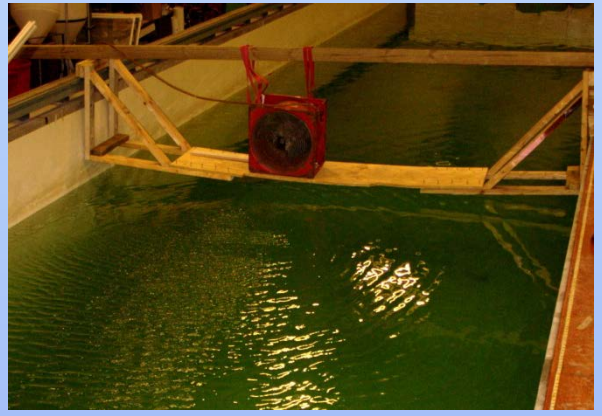


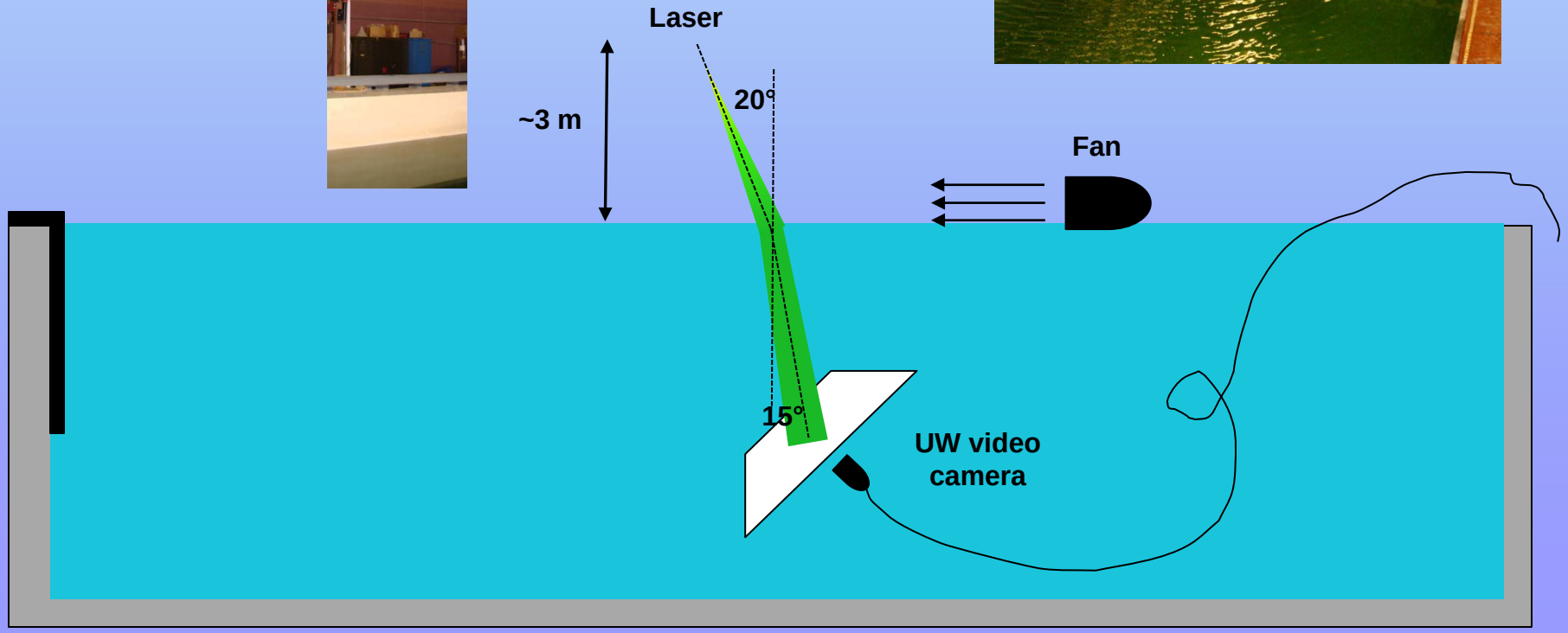
Wave and tow tank



Water Surface Experiments

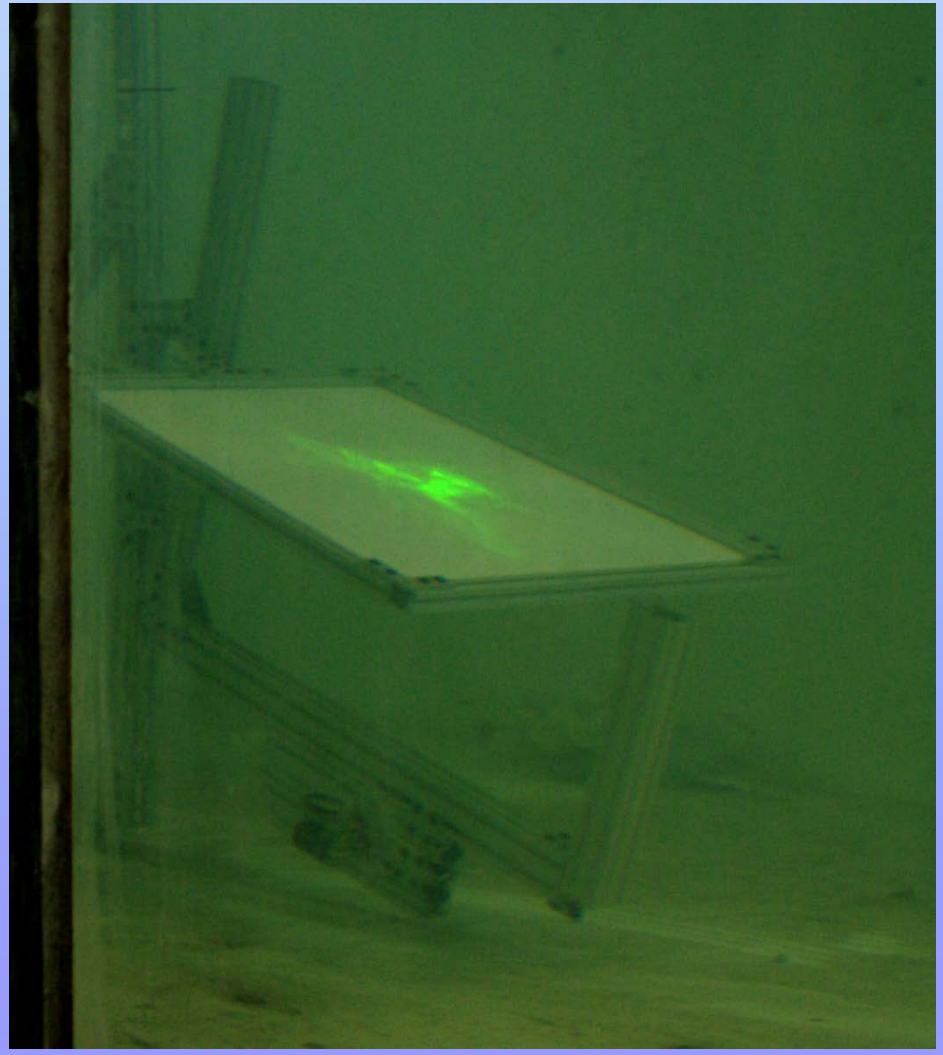






Experiment Verification

- **Capture refracted footprints.**
- **Find the average position of the intensity profiles.**
- **Create a position distribution.**
- **Recreate the experiments in the simulation model.**



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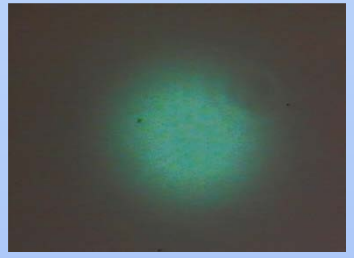
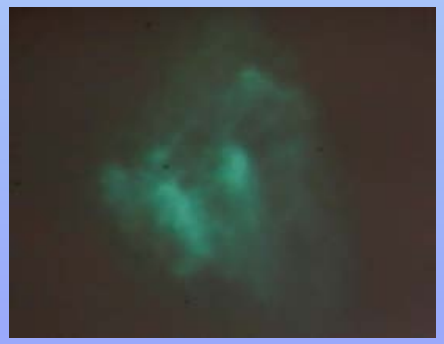
Beam

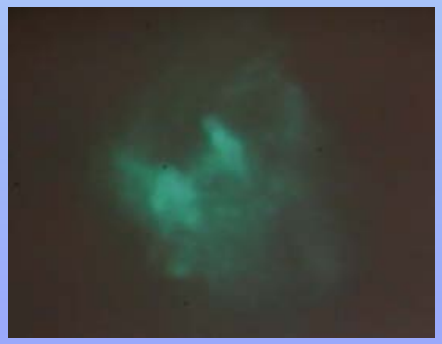
No wind



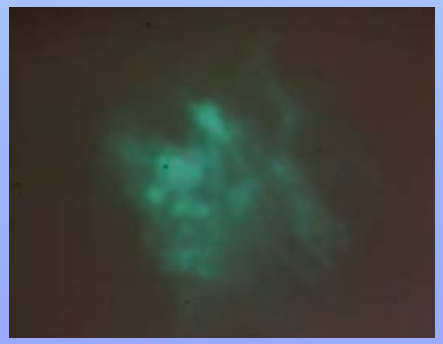
Wind speed = 4 m/s



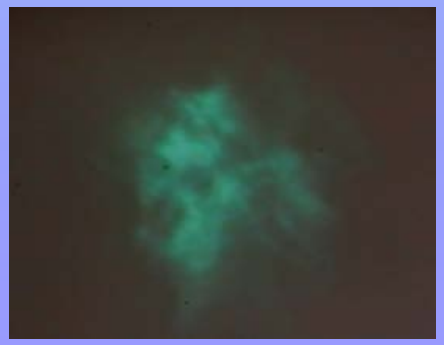
t_1



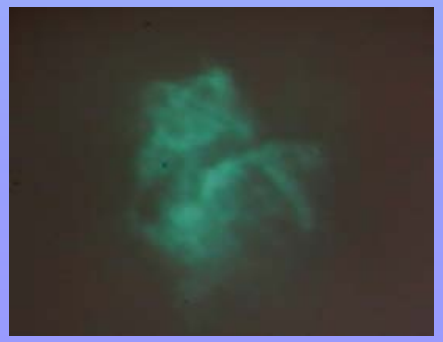
t_2



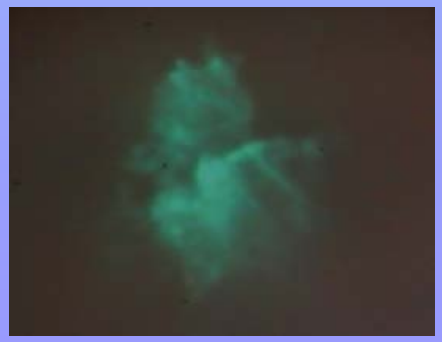
t_3



t_4



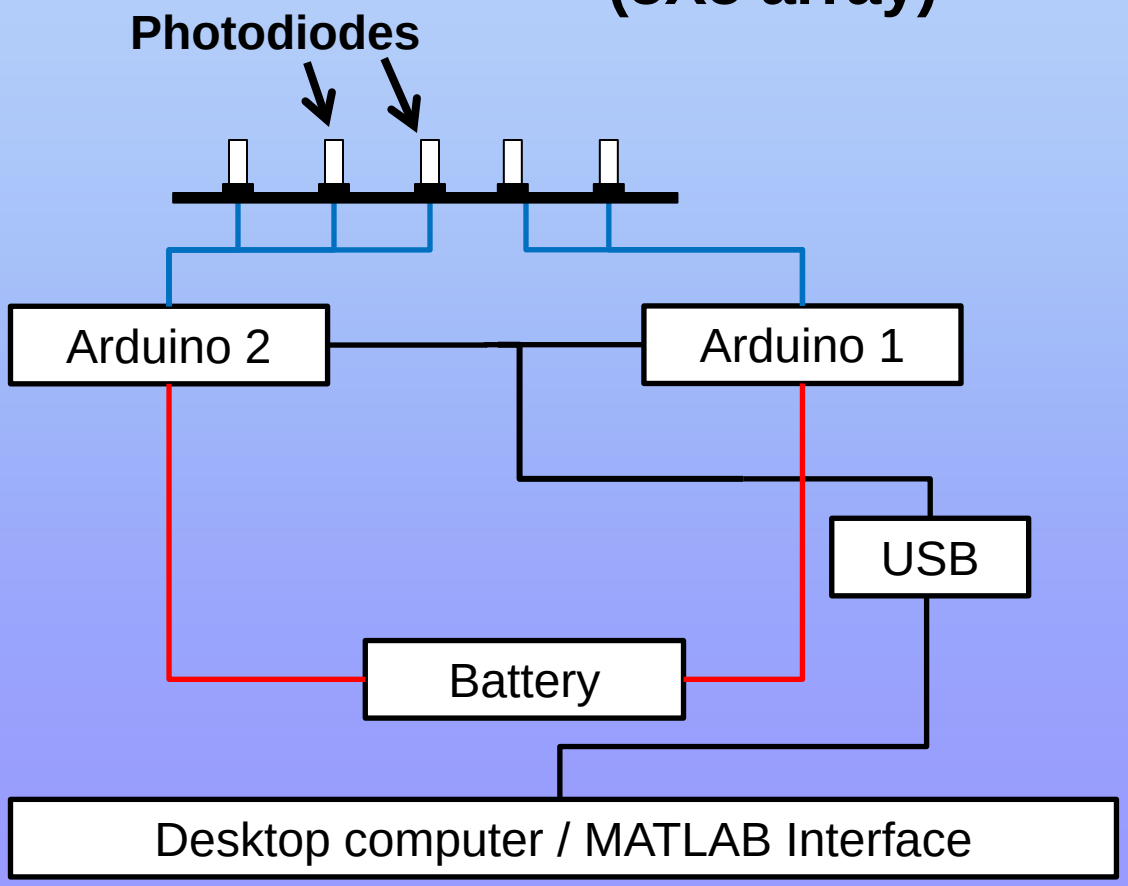
t_5

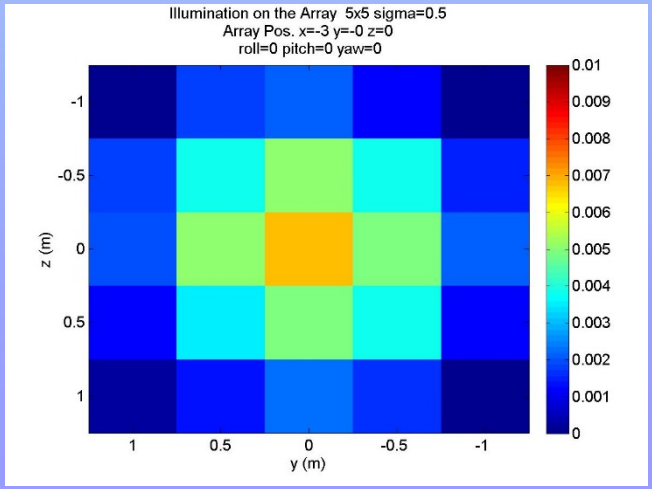


t_6

Detector Array Concept

OPTICAL MODULE (5X5 array)





Water Surface Experiments

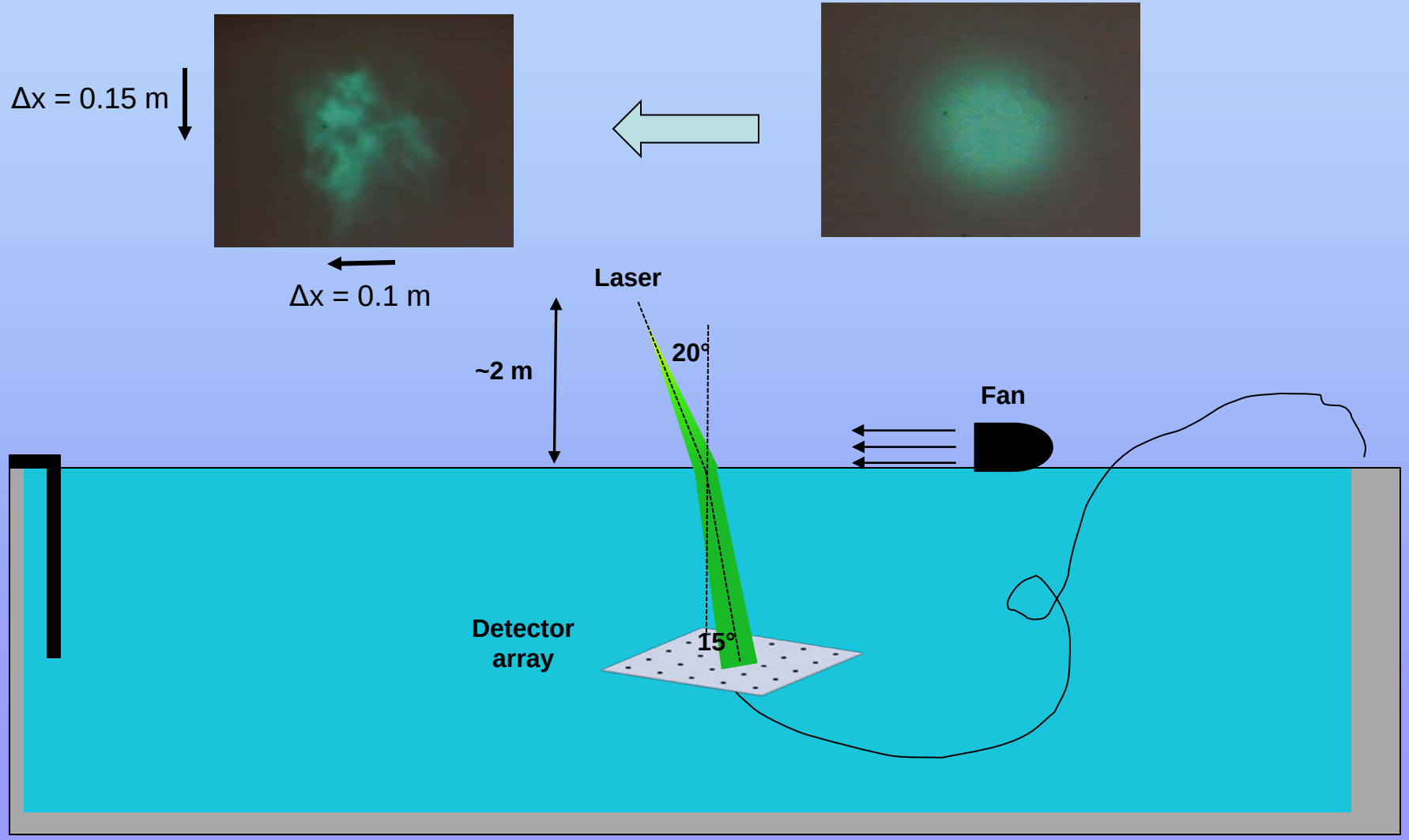


Image Moments Invariants (Pose Estimation)

Algorithm

Sub-pixel accuracy

$$M_{pq} = \frac{1}{S}\sum_{i,j}(y_i - y_o)^p (z_j - z_o)^q I_{i,j}$$

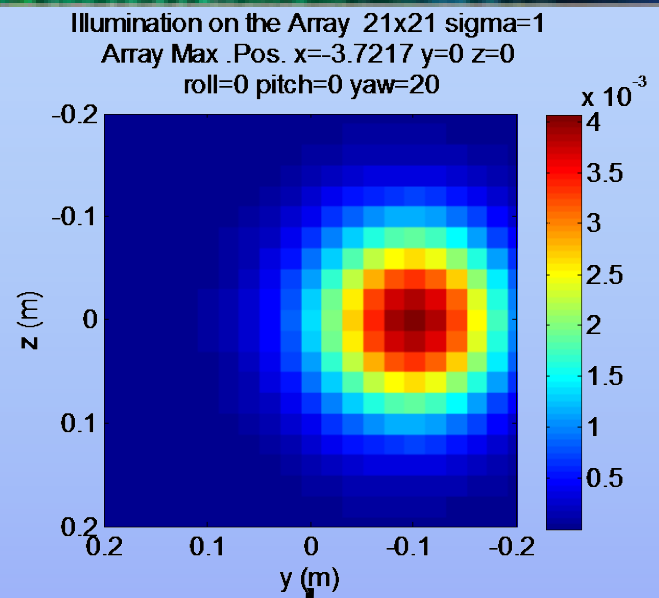
$$S = \sum_{i,j} I_{i,j}$$

$$P_{max} = (y_o, z_o)$$

$$p, q = order\ number$$

$$\frac{M_{23}}{M_{33}} = y - axis$$

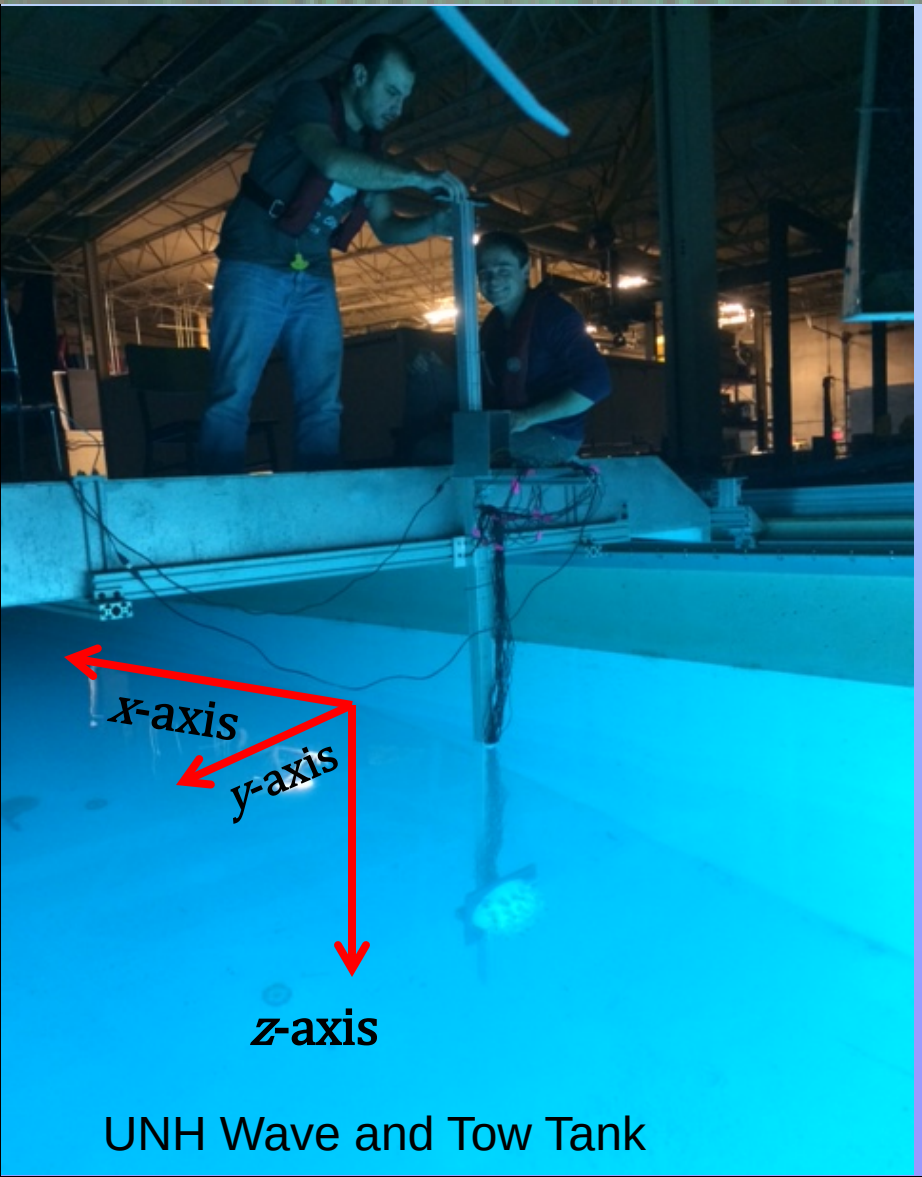
$$\frac{M_{32}}{M_{33}} = z - axis$$



Moment Invariants Table for a pose

1.000	0.000	10.327
-0.522	0.001	-6.754
9.511	-0.023	101.821

Pose Calibration



UNH Wave and Tow Tank

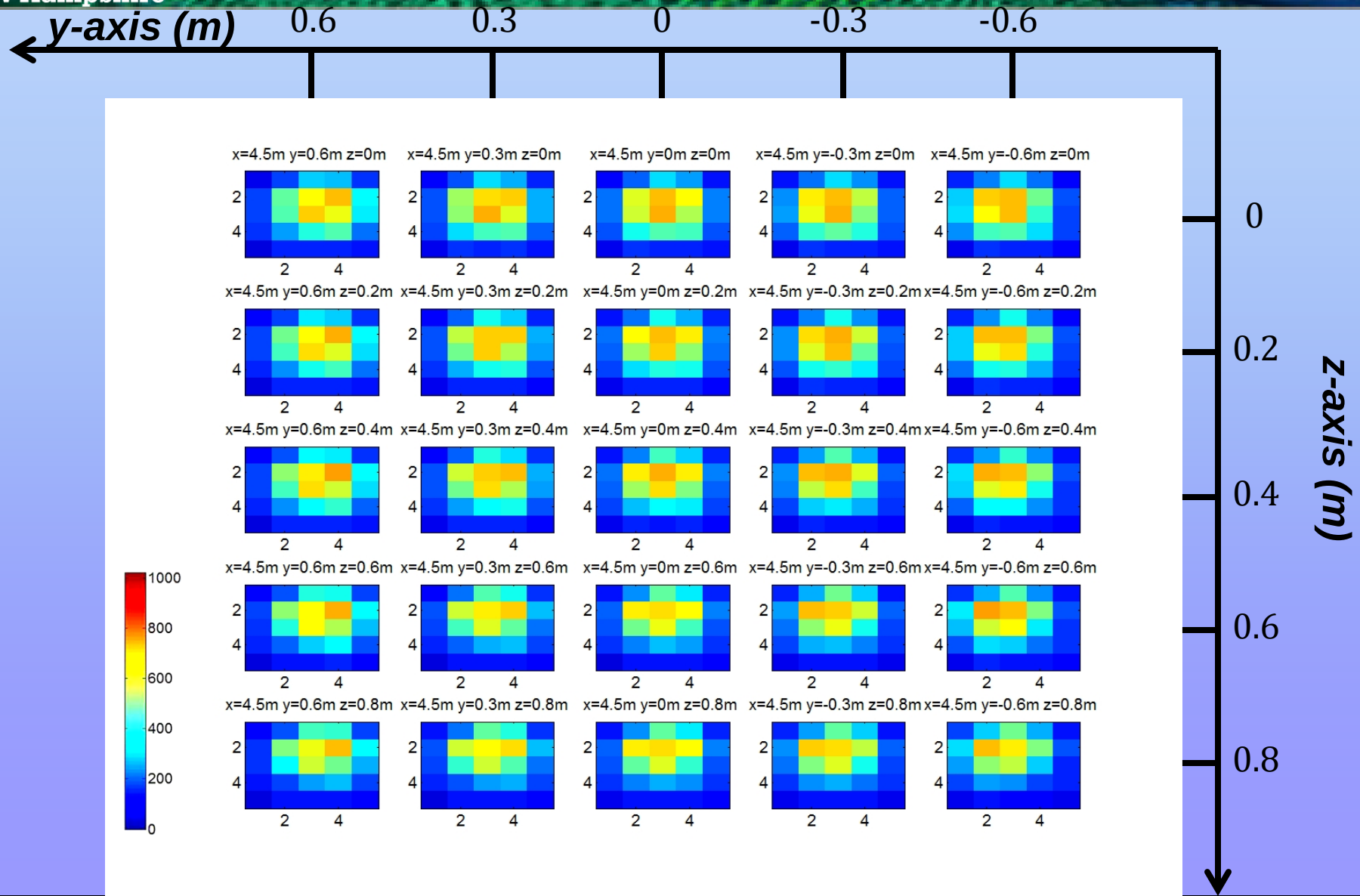
Pose Calibration Geometry

x (m)	4.5	5.5	6.5	7.5	8.5
y (m)	-0.6	0.3	0	0.3	0.6
z (m)	0	0.2	0.4	0.6	0.8

- **Total of 125 positions**
- **200 measurements per positions.**

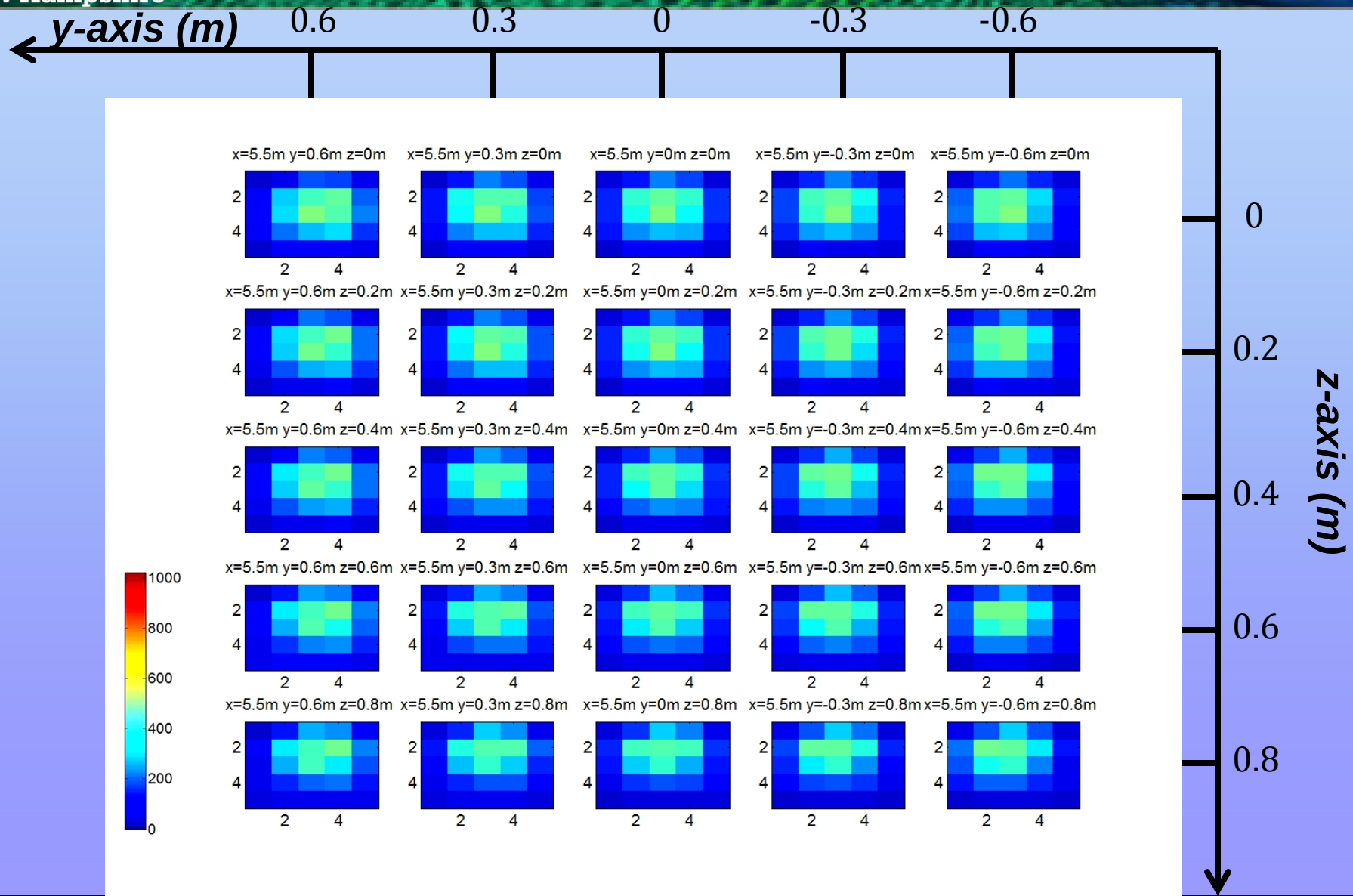
Pose calibration results

X =4.5 m



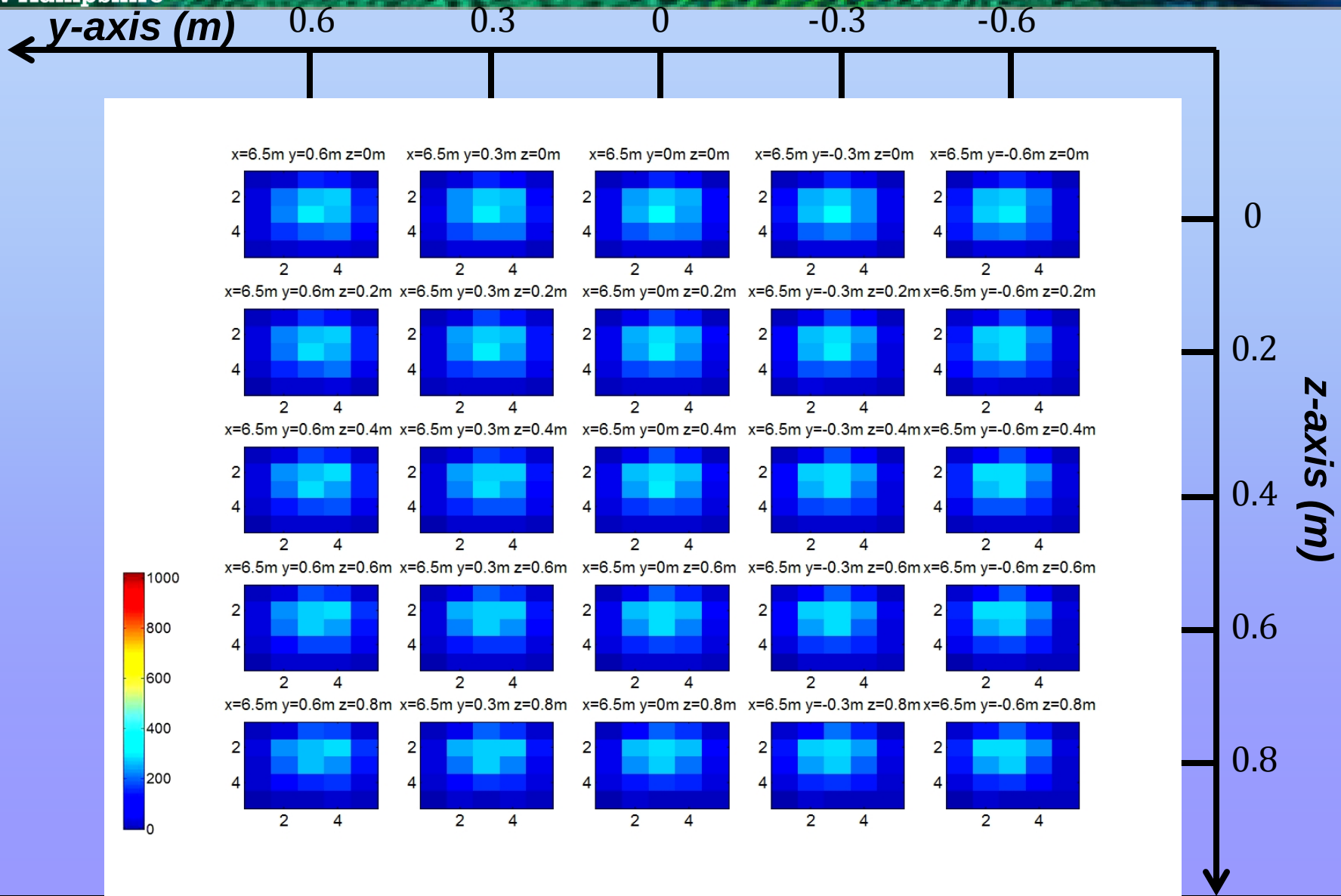
Pose calibration results

X =5.5 m



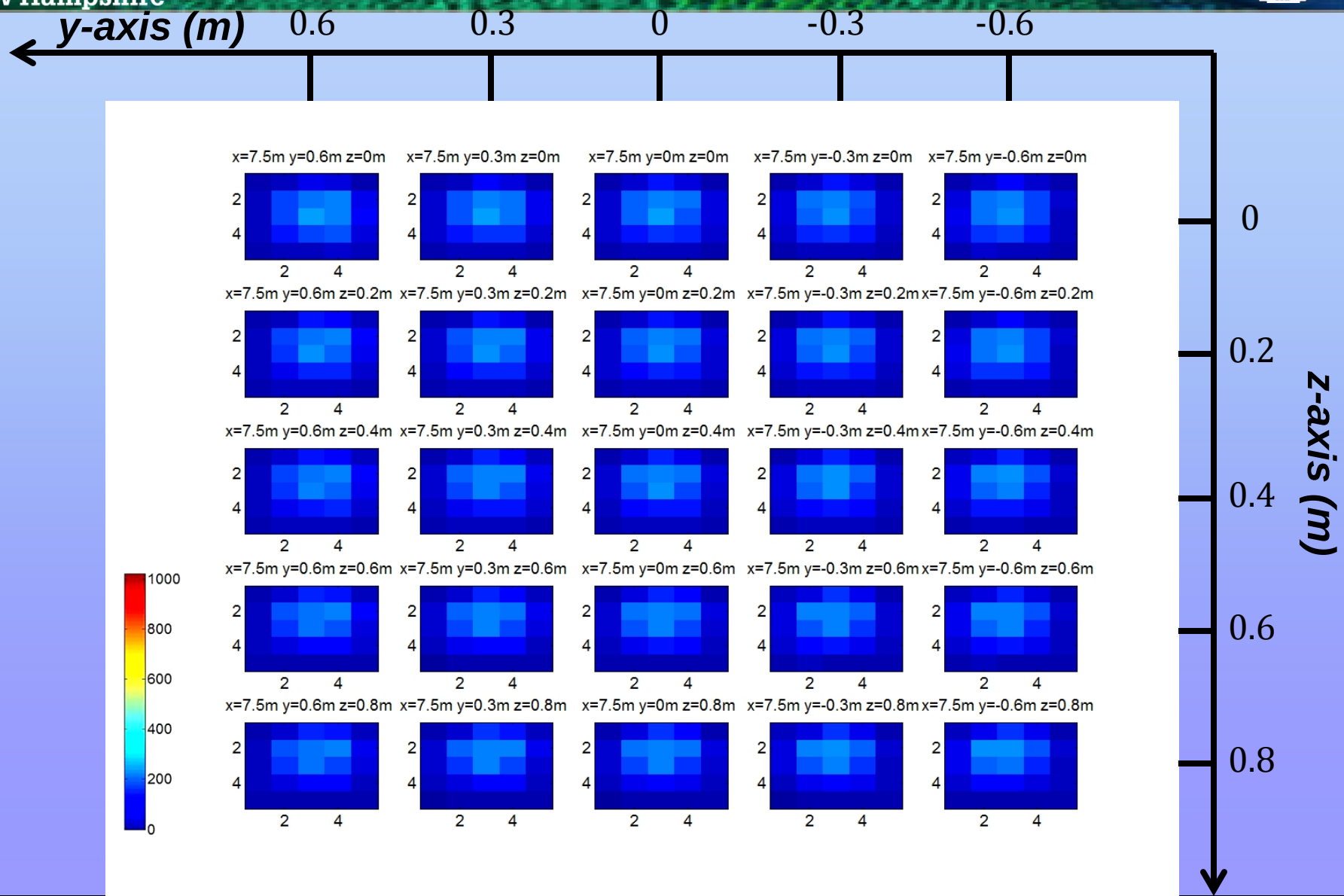
Pose calibration results

X =6.5 m



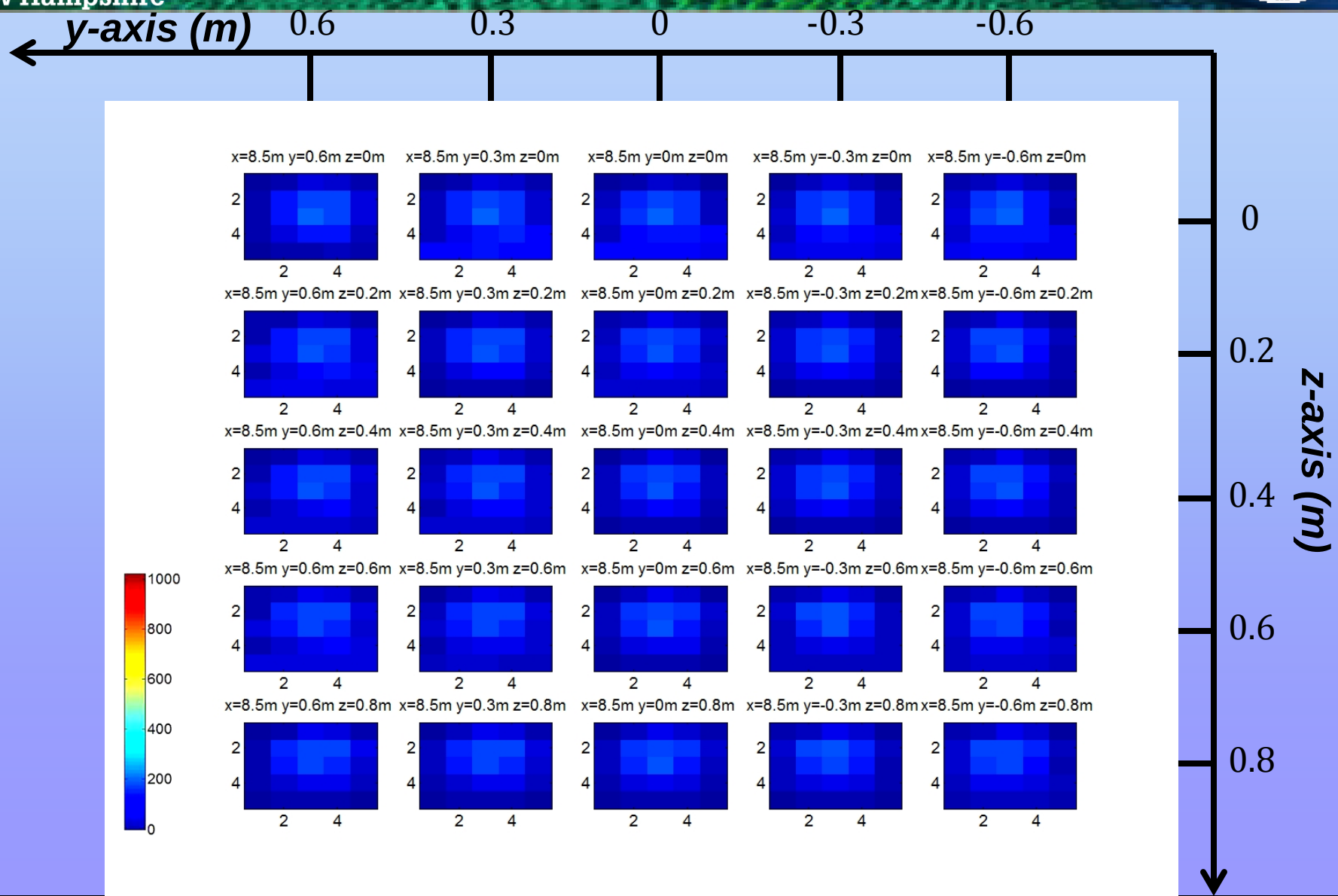
Pose calibration results

X =7.5 m



Pose calibration results

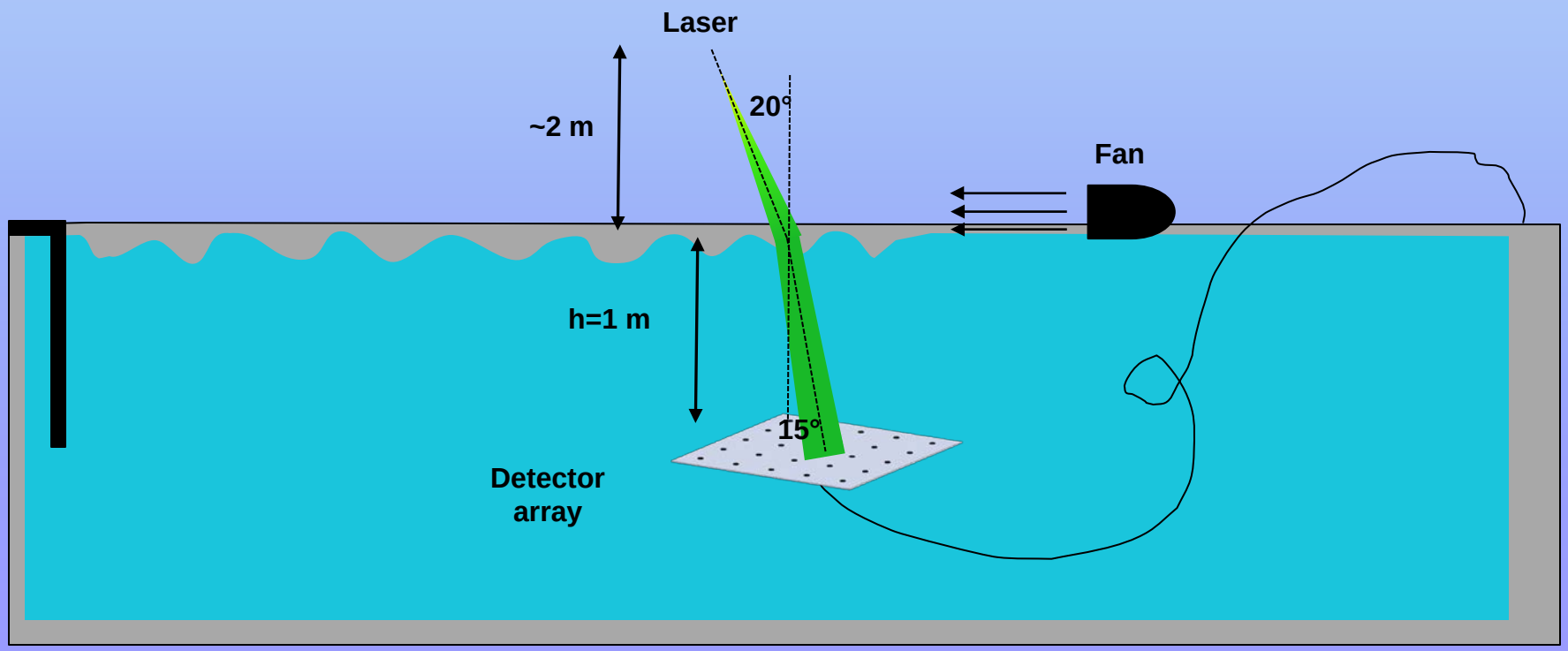
X =8.5 m



Discussion
(interference with the measurements)

$$h > \frac{L}{2}$$

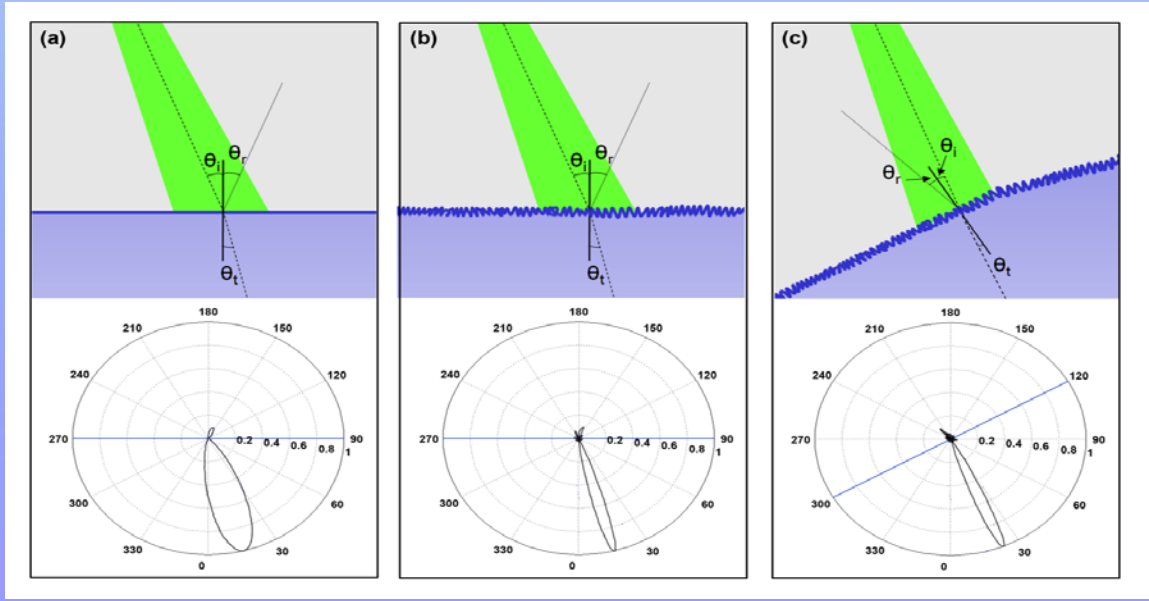
Limited to wavelengths less than 2m



Discussion

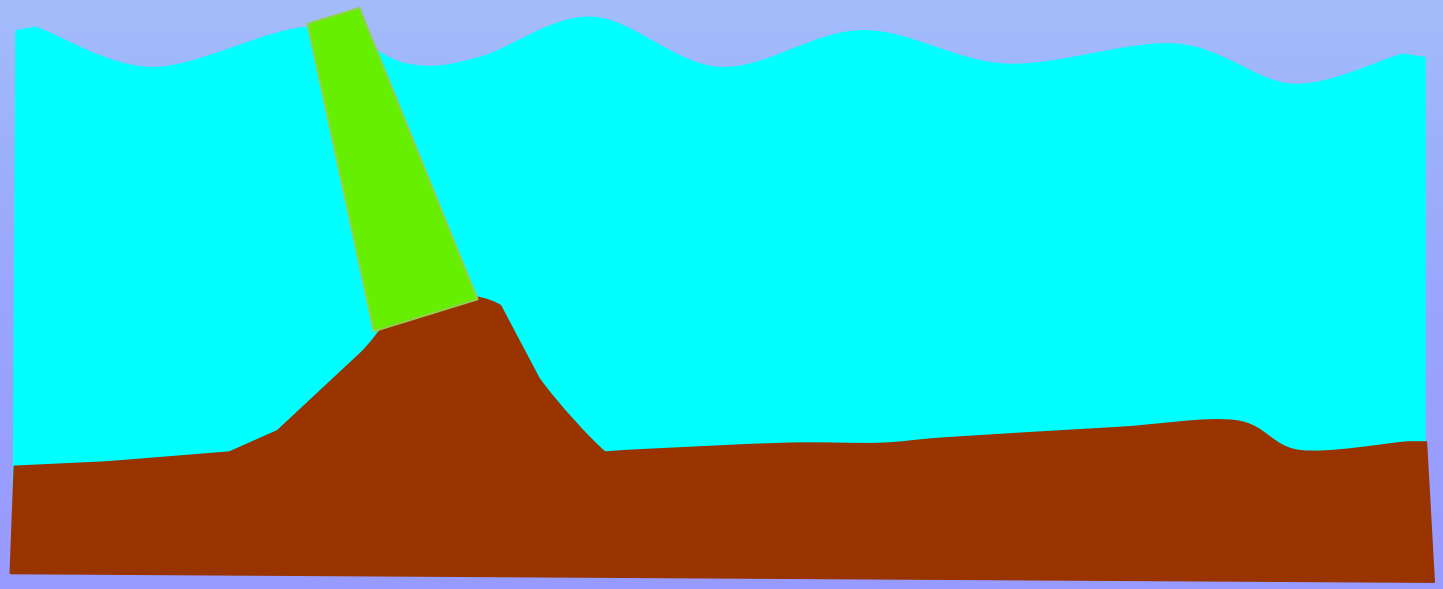
The performance of the system…

- Water surface
  - Effect of gravity waves on beam footprint



Discussion

- Water column and bottom (Dr. Firat Eren)
  - Transformation of laser beam through the water column



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