Schlieren Results from Linac Experiment

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Absorber Review
Fermilab

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Muon Collaboration

Issue: Convection / Forced Flow in LH_2

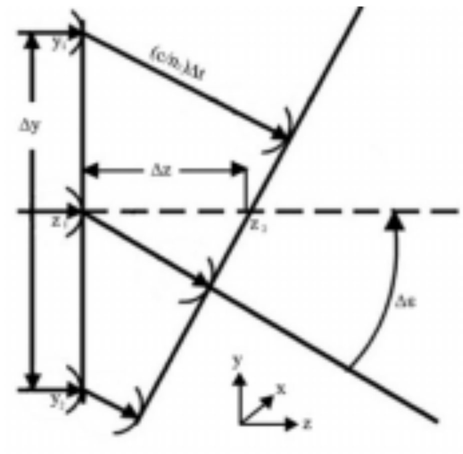
We are looking at convective flow of water in response to an electron beam as a model for LH2.

Water is sufficient for modeling convection:

	H_2O	LH_2	
ρ	1.00	0.070	g/cm^3
n	1.33	1.109	
c_p	1.00	3.44	Cal/g^oK

Schlieren Refraction

Optical inhomogeneities refract light in proportion to their gradients of refractive index.



Assume a gradient in the y-direction. Light is initially horizontal (along the z-axis). As it passes through the object (Δz) it gets refracted through the angle Δε.

From the above figure, we have the equation:

$$\Delta\varepsilon = \frac{\left(\frac{c_0}{n_2} - \frac{c_0}{n_1}\right)\Delta t}{\Delta y}$$

We also have:

$$\Delta t = \Delta z \frac{n}{c_0}$$

Hence,

$$\Delta\epsilon = \frac{n}{c_0}\frac{\left(\frac{c_0}{n_2} - \frac{c_0}{n_1}\right)\Delta z}{\Delta y}$$

This shows

$$\Delta\epsilon = \frac{n}{n_1 n_2}\,\frac{(n_1 - n_2)\Delta \mathbf{z}}{\Delta y}$$

So, as $\Delta y \to 0$,

$$\frac{d\varepsilon}{dz} = \frac{1}{n}\,\frac{dn}{dy}$$

Since ε is a very small angle, it is approximately the slope, which is dy/dz. Changing to partial derivatives gives:

$$\frac{\partial^2 y}{\partial z^2} = \frac{1}{n}\,\frac{\partial n}{\partial y}, \quad \frac{\partial^2 x}{\partial z^2} = \frac{1}{n}\,\frac{\partial n}{\partial x}$$

Sensitivity

- The sensitivity of the system is set by considering the deflection of the image compared to the pinhole size. The relevant parameter is the contrast,

$$C = \frac{\Delta I}{I} = f\,\varepsilon / a$$

in terms of

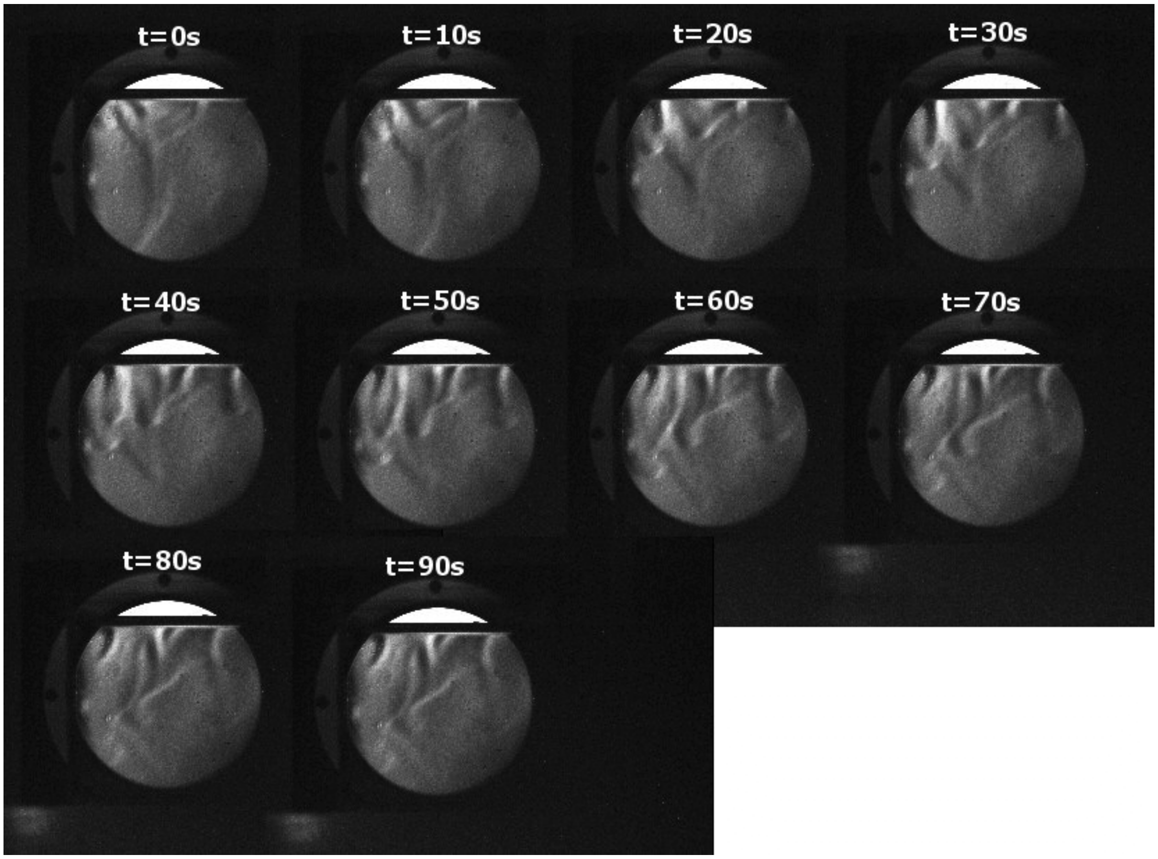
I	light intensity
f	focal length
a	pinhole size

and

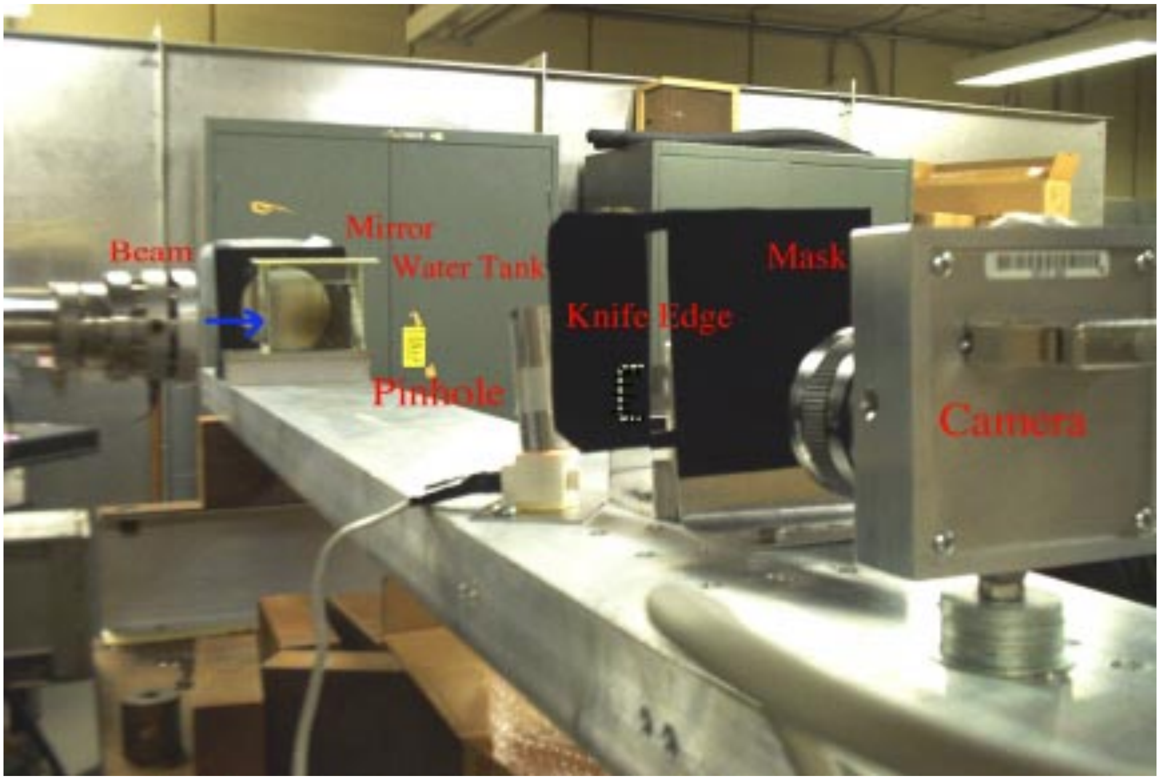
$$\varepsilon_x = \frac{L_z}{n}\frac{\partial n}{\partial x}, \qquad \varepsilon_y = \frac{L_z}{n}\frac{\partial n}{\partial y}.$$

Many systems use refraction angles of 5 - 20 arcseconds.

Quiescent Flow in Water



Experimental Setup



Two Geometries:

- Horizontal knife edge: vertical density variations

- Vertical knife edge: horizontal density variations

- Beam conditions
  - 18 MeV beam
  - 200 pulses
  - 4ns each
  - 30nC/pulse

- Range of electrons is approximately 9 cm in water

- Chamber is 10 cm long

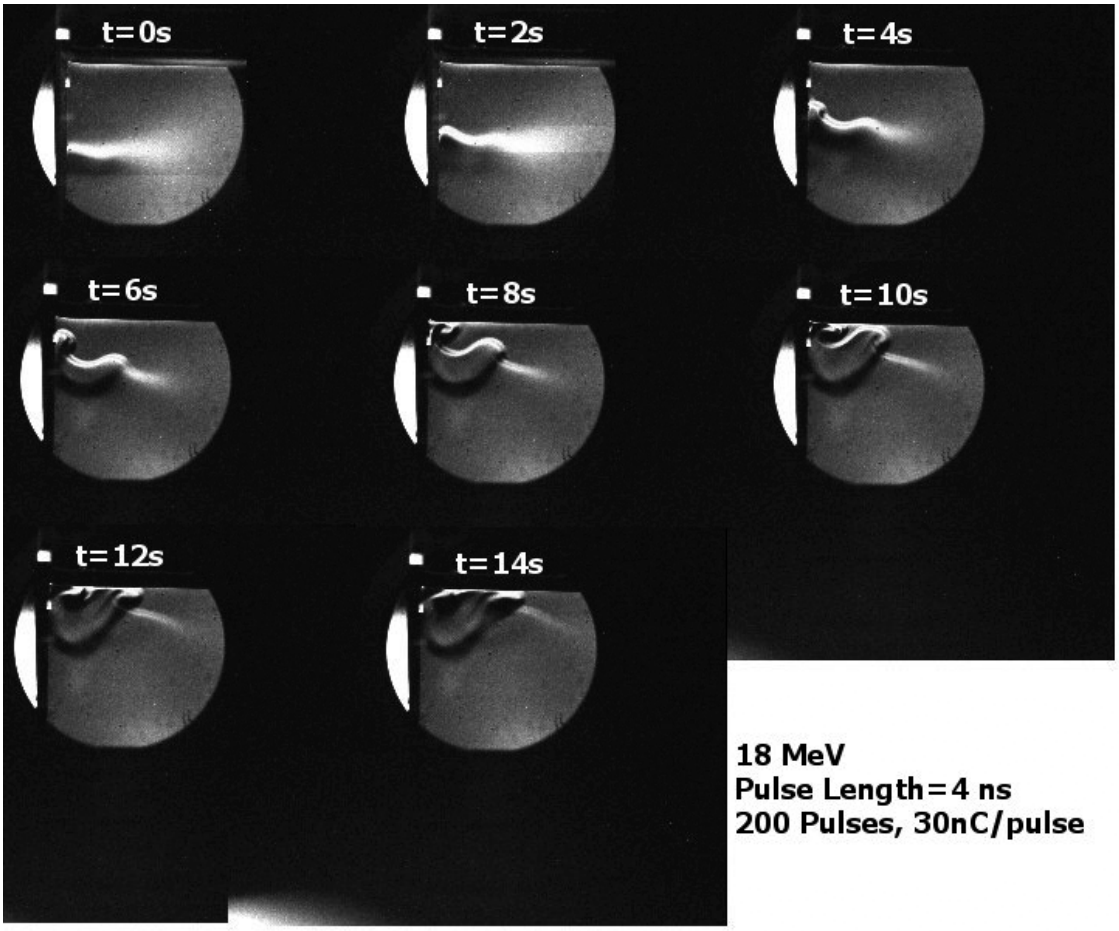
Will present

- Pictures of beam induced turbulence

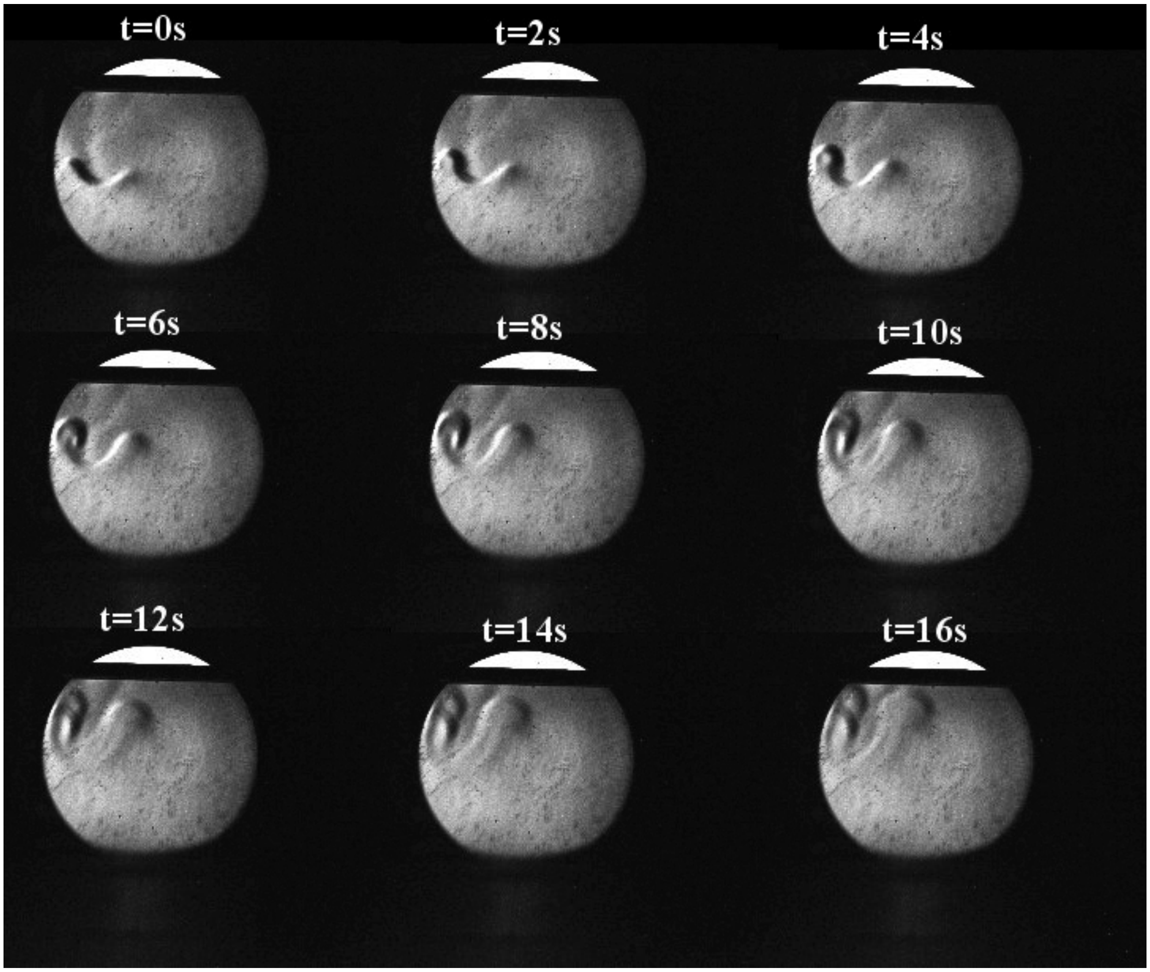
- Spatial variation

- Time development

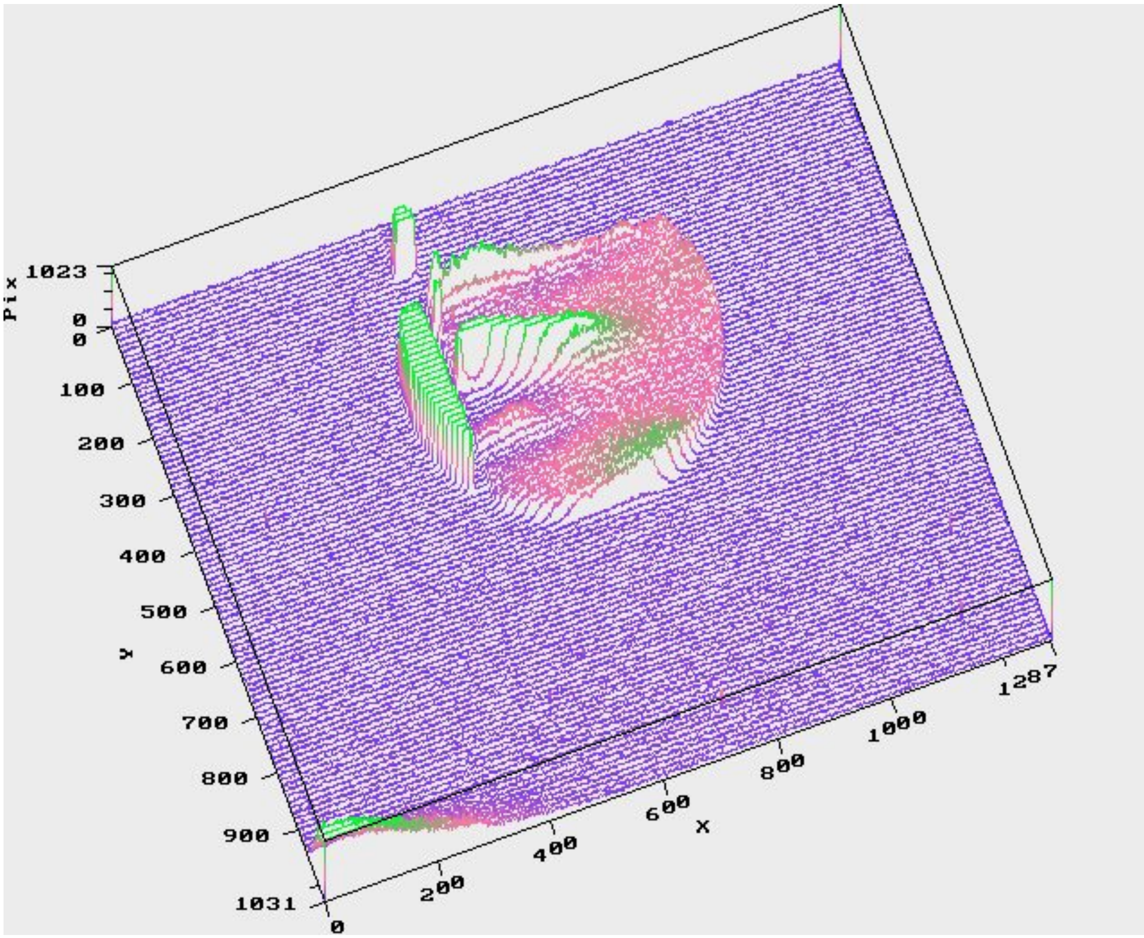
Horizontal knife edge / Vertical gradients



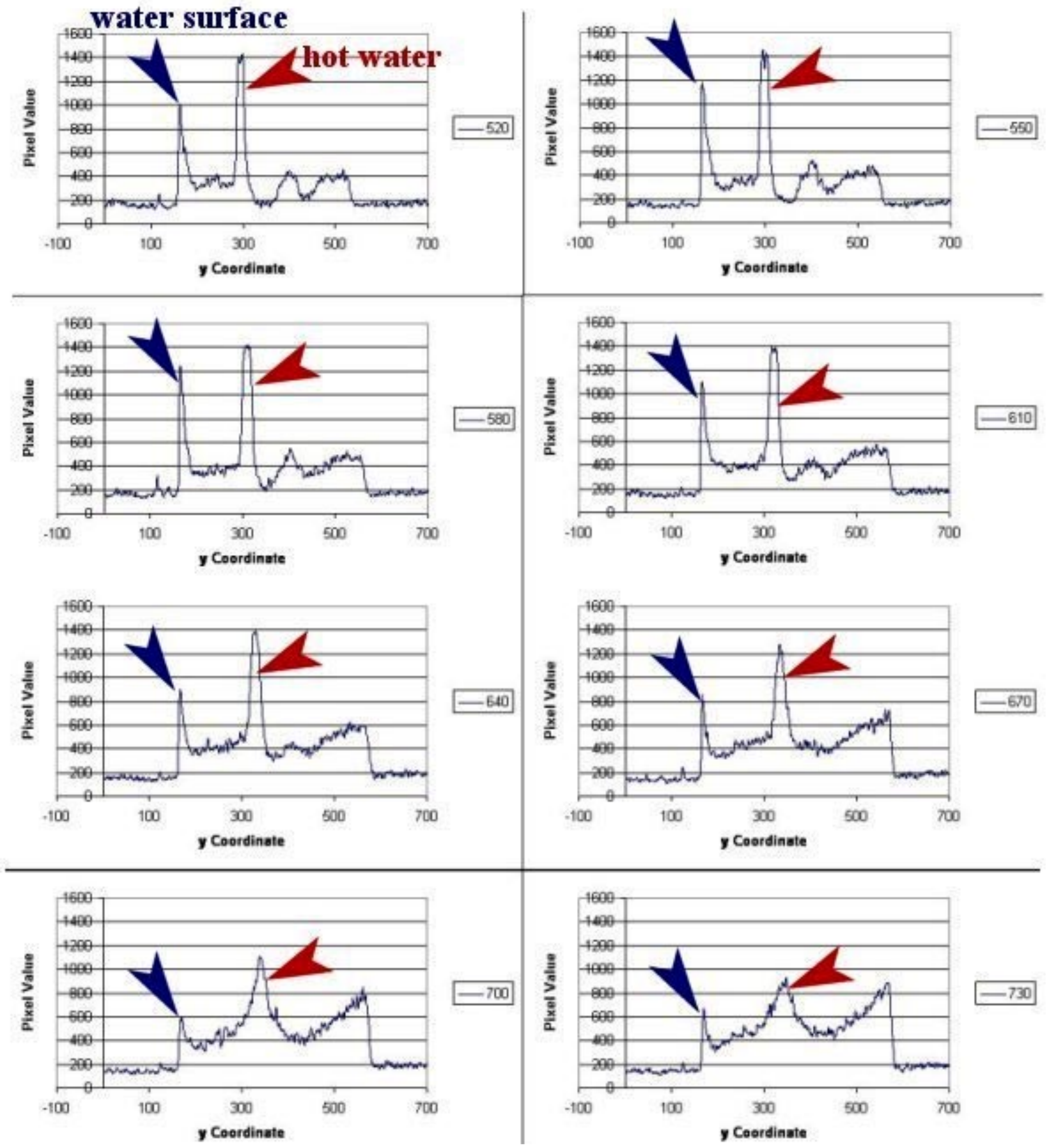
Vertical knife edge /Horizontal gradients

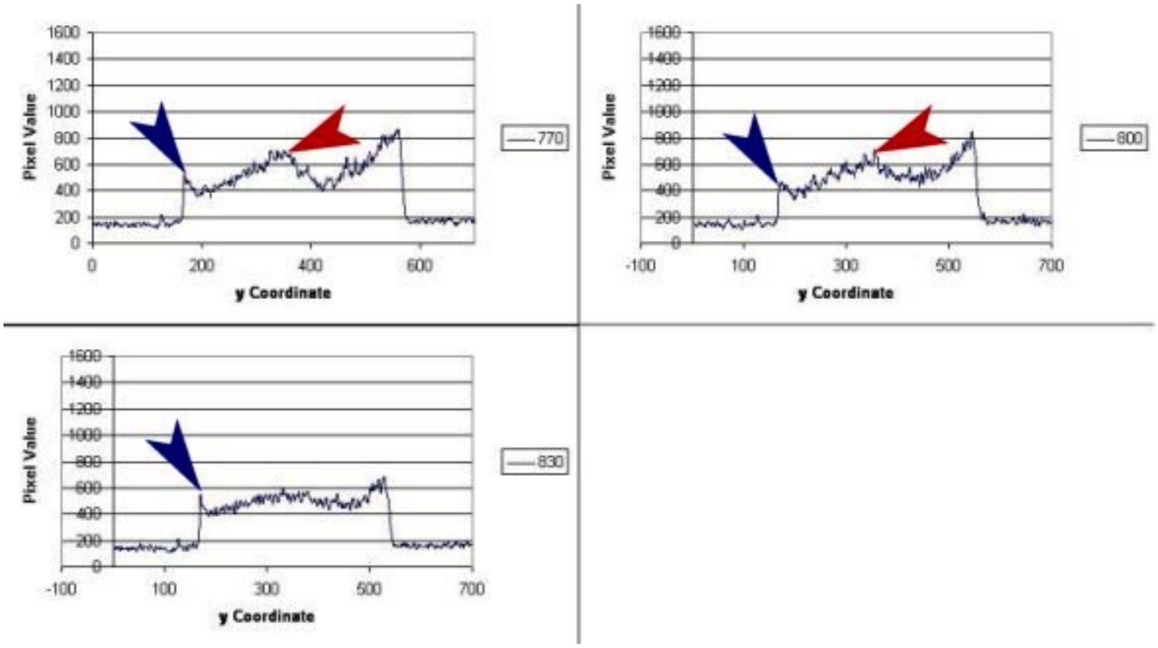


Optical Density in Digital Camera

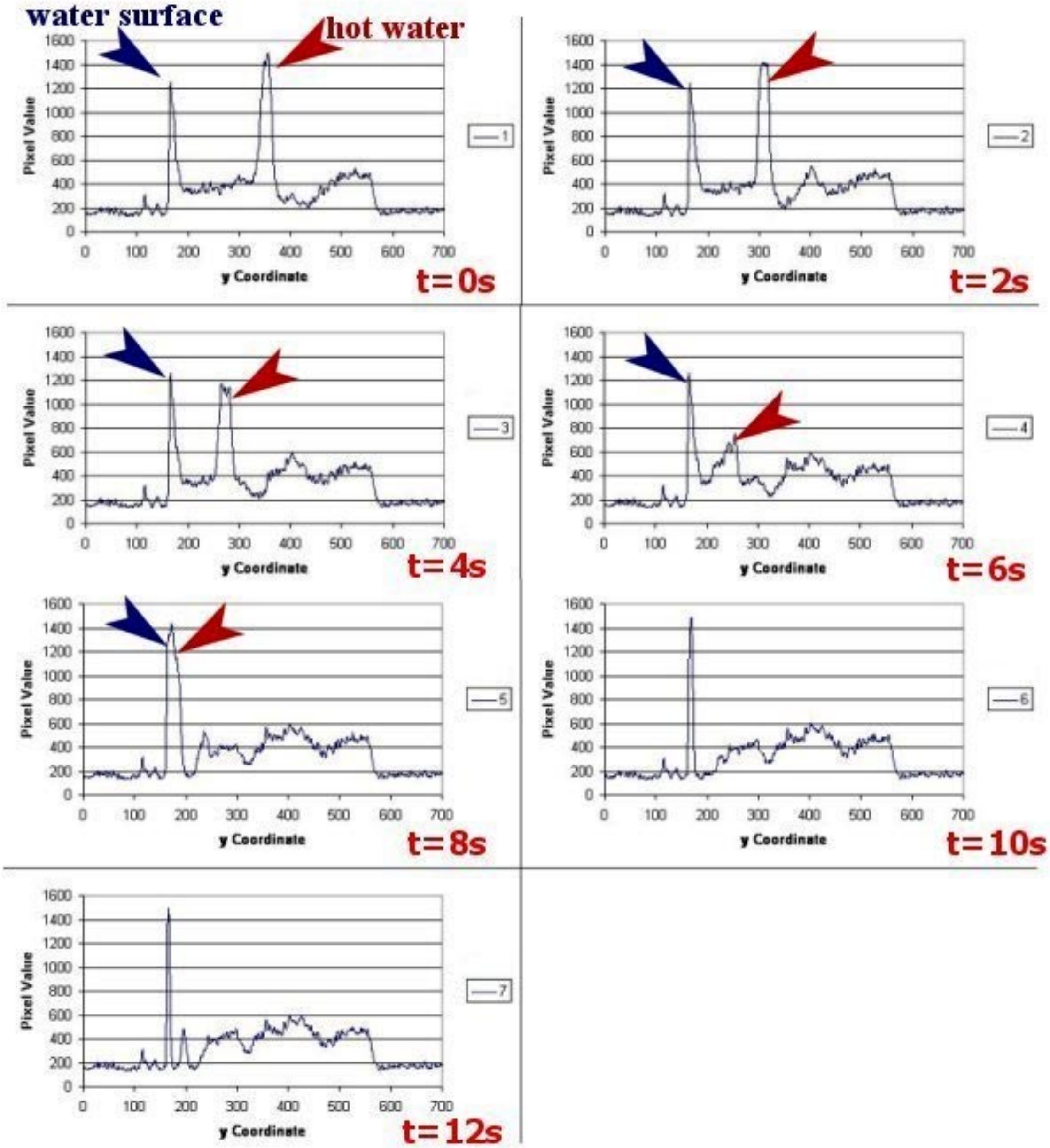


Spatial Slices



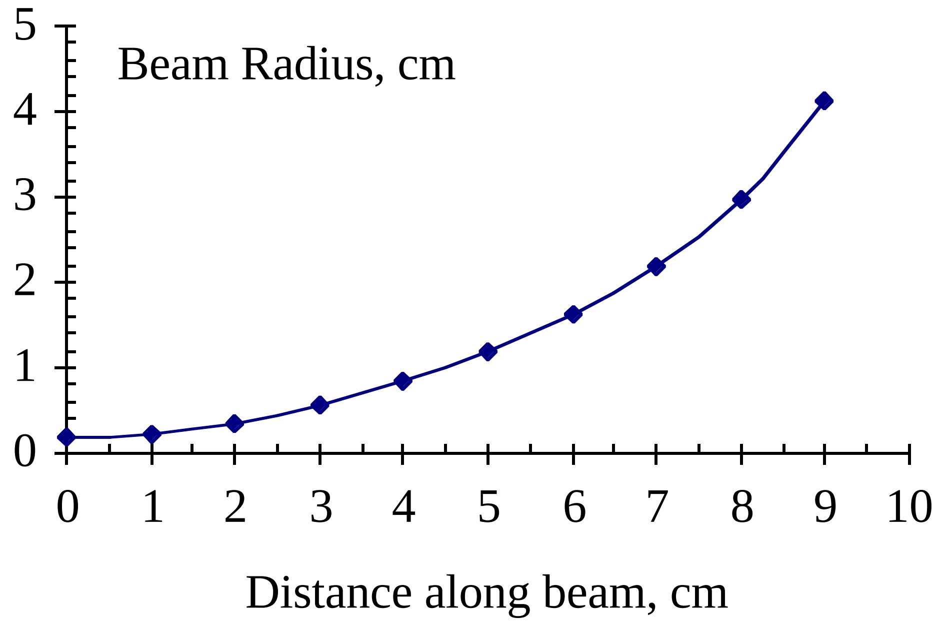

Pixel Value
y Coordinate
770
800
830

Temporal Slices



Beam Dimensions

- We did not tune the beam, so the dimensions were small where it entered the chamber and then it diverged according to multiple scattering. The approximate dimension as shown.



Improvements to Beamline Setup

- Need more mechanical tuning knobs

- Increase beam size to match calculations

- Fiducials on tank for precision measurements

- Brighter light for more sensitivity

- Use of quartz to avoid browning of glass

- Understand camera and software better
    - Find appropriate settings on software for better images
    - Use of digital zoom on camera
    - Other options for camera

- Trigger on electron beam

Matching Experiment with Model

- Comparison of data with computer models will involve changes in geometry. We need a round chamber with the beam parallel to the optical path.
- Friction effects near surfaces can be experimentally measured
- Startup/steady state issues can be studied

Steady State (with beam perpendicular to figure):

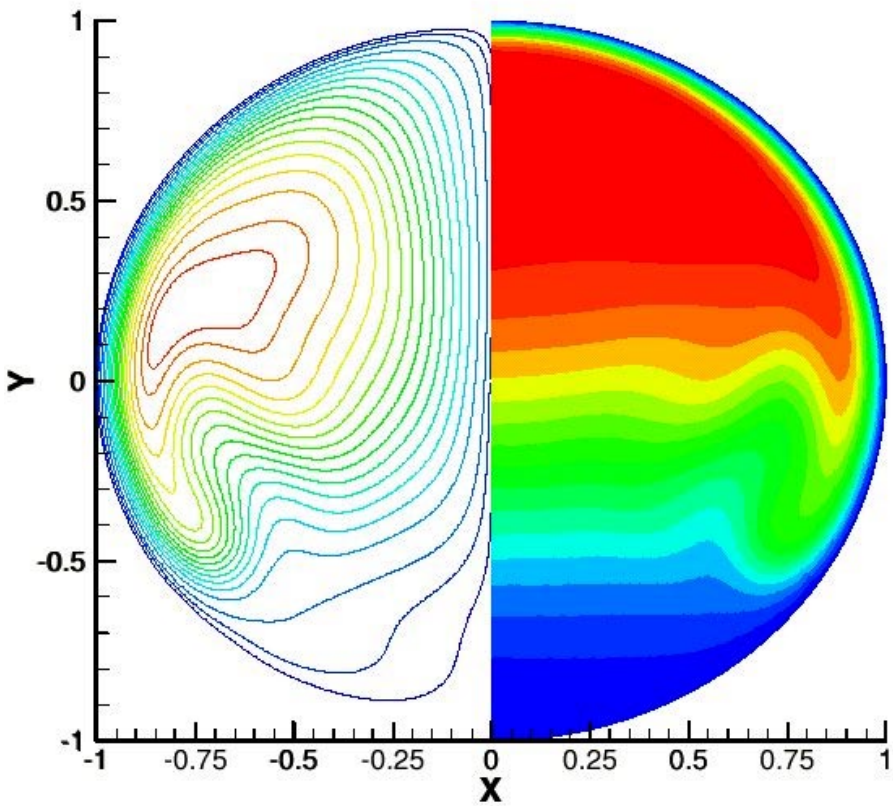


Figure courtesy of Kevin Cassel.

Costs

• Quartz/optics shop	1 k
• CD burner	0.2 k
• Beam time	1 k/day
• Thermocouples	0.5 k
• Shop Work	2 k
• Optics	1 k

Summary

- We have constructed a sensitive Schlieren system which can see a variety of hydrodynamic effects in water.

- An initial test with an electron beam has shown a large signal with which we have been making preliminary measurements and checking out the system.

- We will continue improving the system and begin tests with realistic geometries.