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# Measurements of Turbulence Correlations in Low Atwood Number Rayleigh-Taylor Mixing

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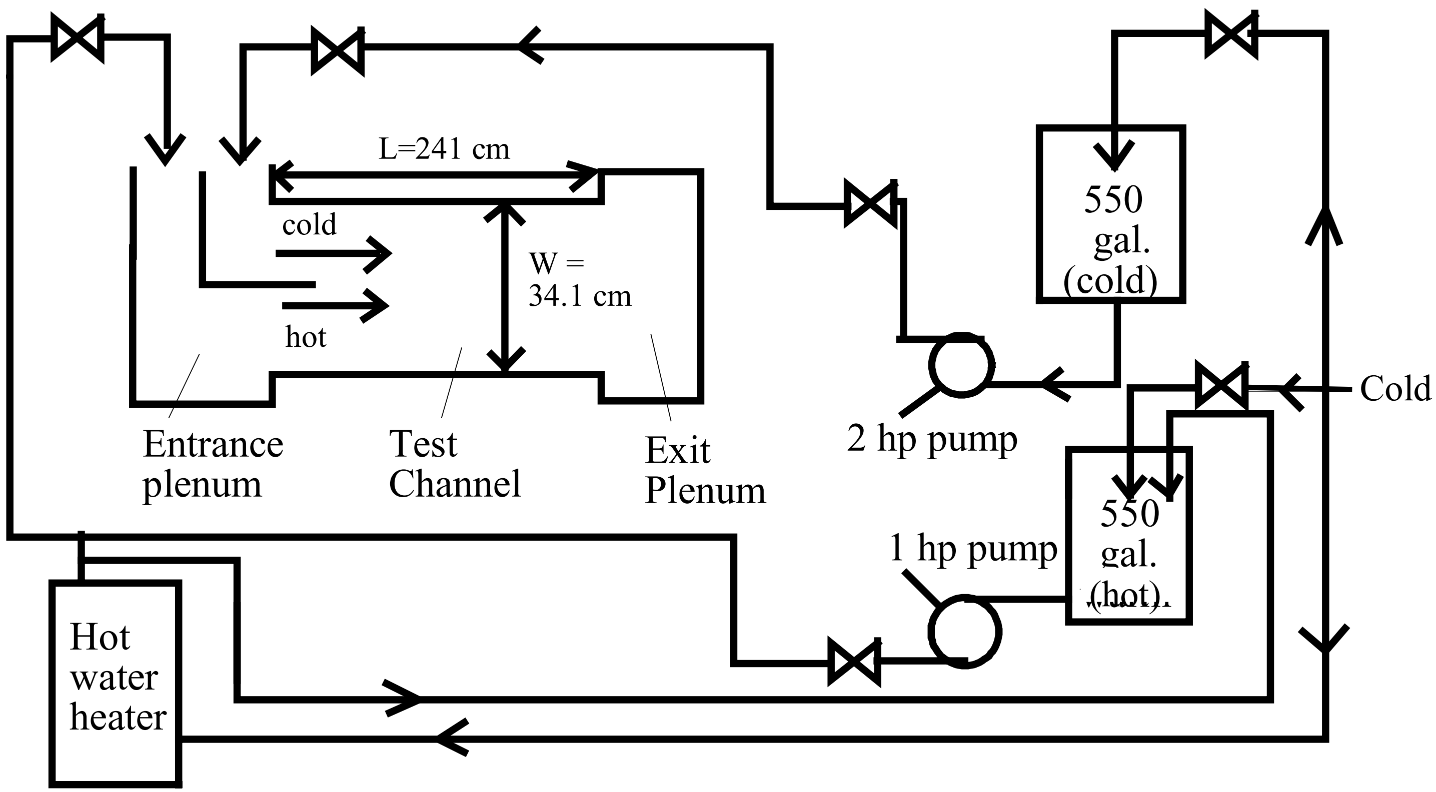
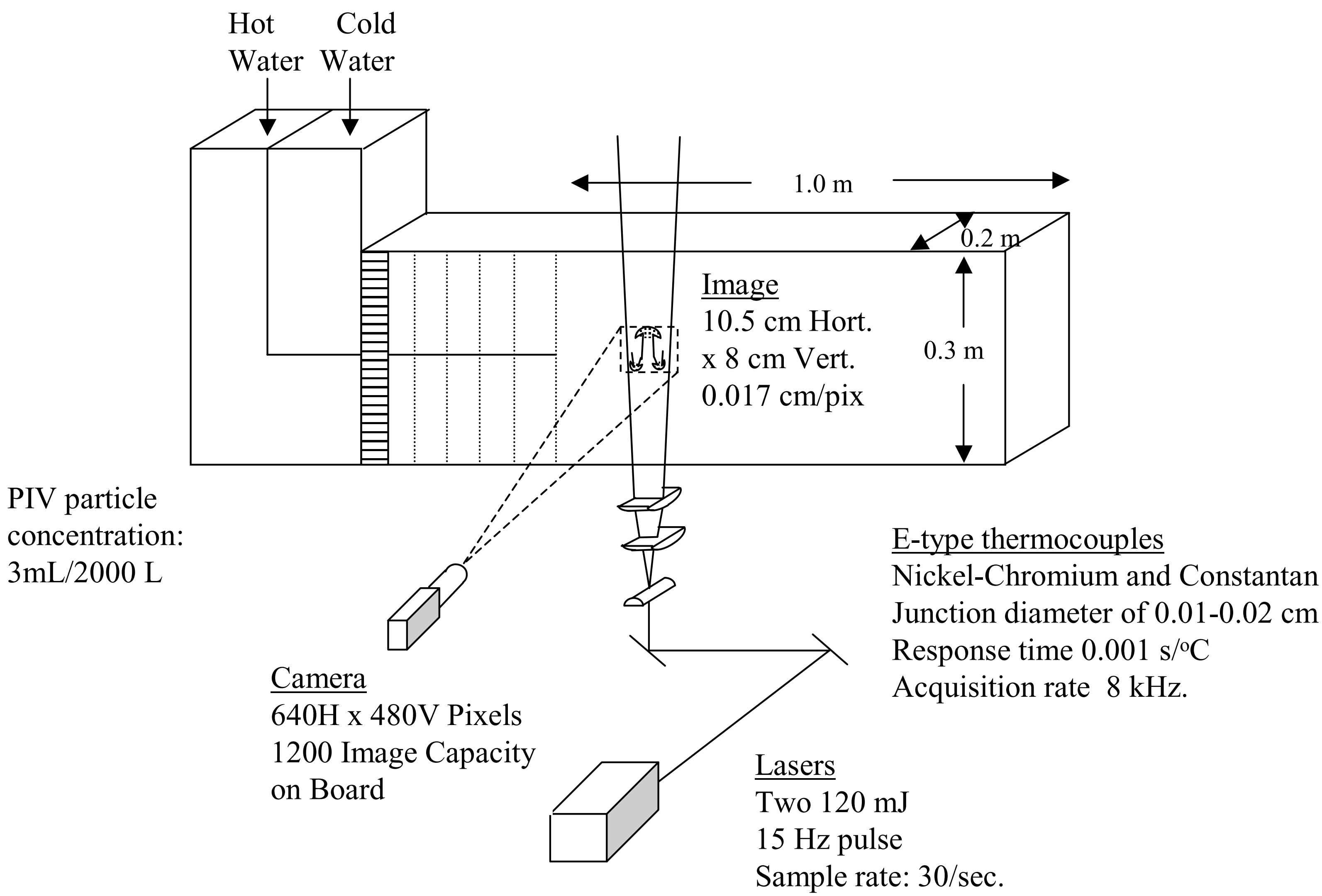
# Overview

- Detailed measurements of turbulent Rayleigh-Taylor have been taken in support of mix models for the description and understanding of hydrodynamic instabilities that develop during the implosion phase of ICF capsules.
- Highlights include: extensive collection of data and development of the PIV-S method.
- The intent is data to aid in the development of statistical turbulence models
- What follows is a selection of our results.

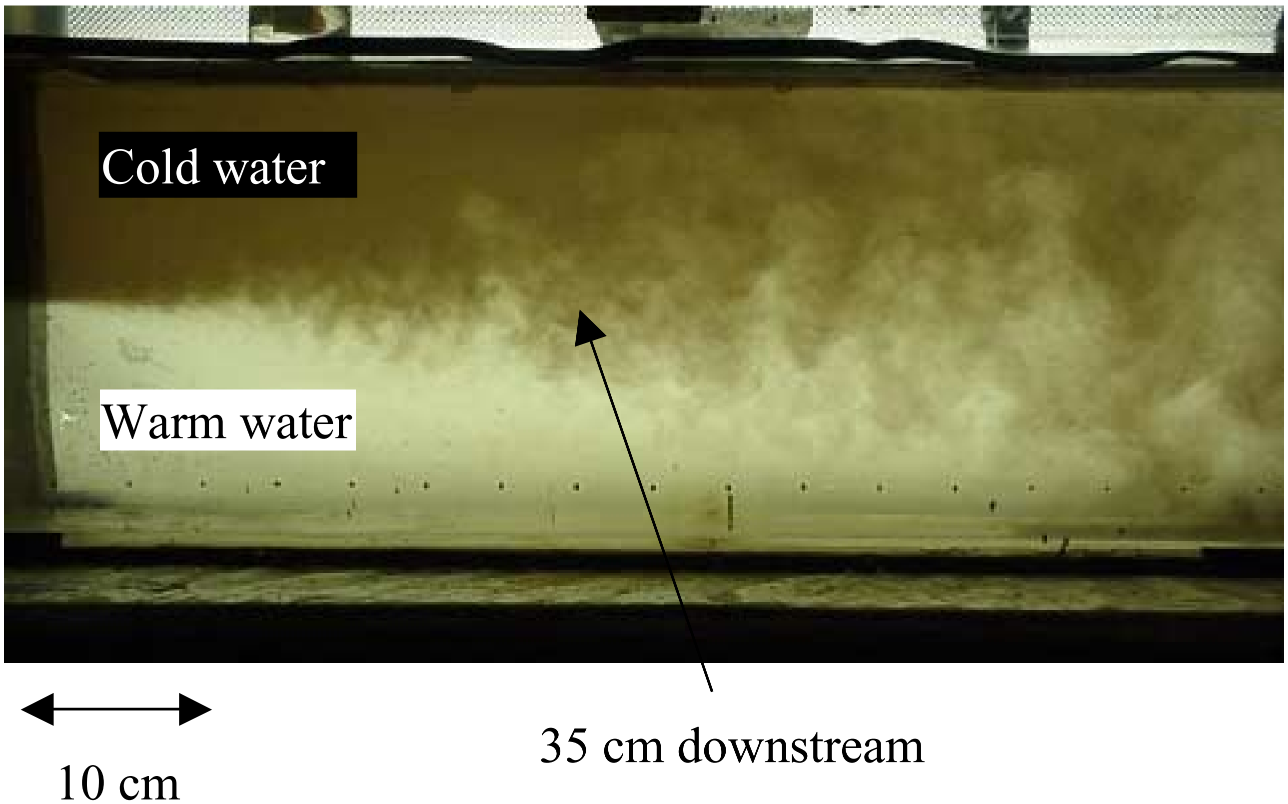
# Schematic of experiment



# Experimental details



# Photograph from experiment




At # = $10^{-3}$

$\Delta T = 5^{o}C$

U = 4 cm/s

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# Summary of data collected

At Atwood numbers of $10^{-3}$ and $5 \times 10^{-4}$:

- Density profiles across mix; width quadratic growth rate, α
- Ensemble averaged measurements of turbulence R-T mixing correlations:

$$\overline{\rho'^2}, \overline{u'^2}, \overline{v'^2}, \overline{u'v'}, \text{and } \overline{\rho' u'}, \overline{\rho' v'}$$

- Turbulence density fluctuation energy spectra.
- Molecular mix fraction, θ
- Anisotropy tensor

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# Parameter definitions

$$B_0 = \lim_{T\to\infty}\frac{1}{T}\int_0^T\left(\rho-\overline{\rho}\right)^2 dt/\Delta\rho^2 = \lim_{T\to\infty}\frac{1}{T}\int_0^T(\rho')^2 dt/\Delta\rho^2$$

$$B_2 = \overline{\rho^*}\left(1-\overline{\rho^*}\right) = f_1\left(1-f_1\right) \qquad \theta \equiv 1 - B_0/B_2$$

$$\rho^* = \frac{\left(\rho-\rho_{\min}\right)}{\left(\rho_{\max}-\rho_{\min}\right)} \qquad \overline{\rho^*} = \frac{\sum_1^n \rho_i^*}{n} \qquad B_0 = \frac{n\sum_1^n \rho_i^{*2} - \left(\sum_1^n \rho_i^*\right)^2}{n(n-1)}$$

$$B_0(\omega_n) = \frac{2\delta t}{N}\left|\sum_{i=0}^{N-1}(\rho_i *)' e^{2\pi j\omega_n t_i}\right|$$

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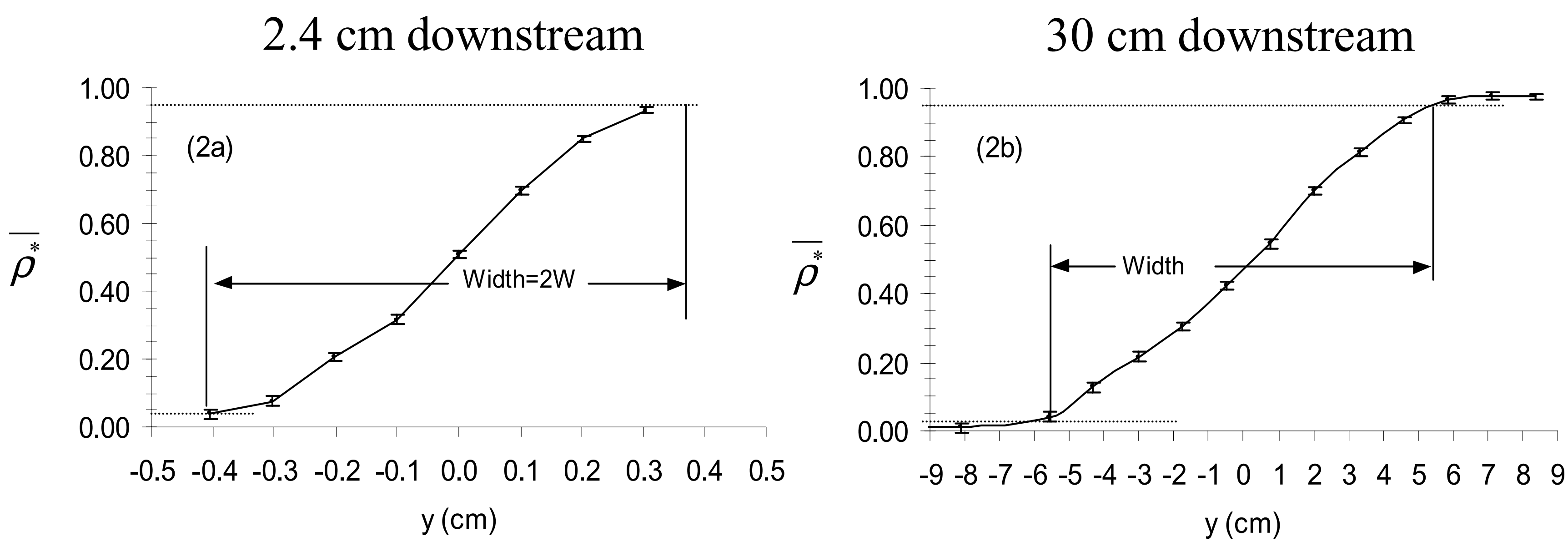
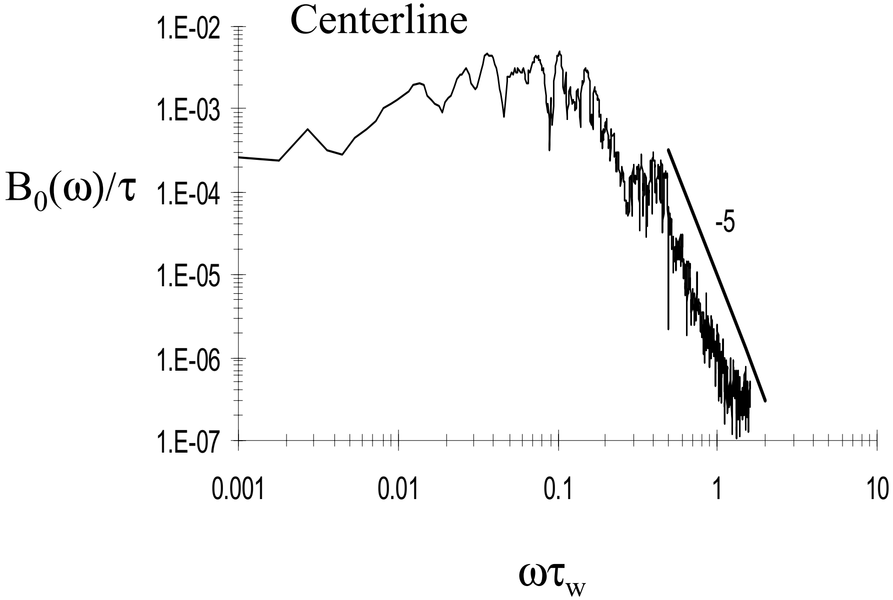
# Mean density profiles



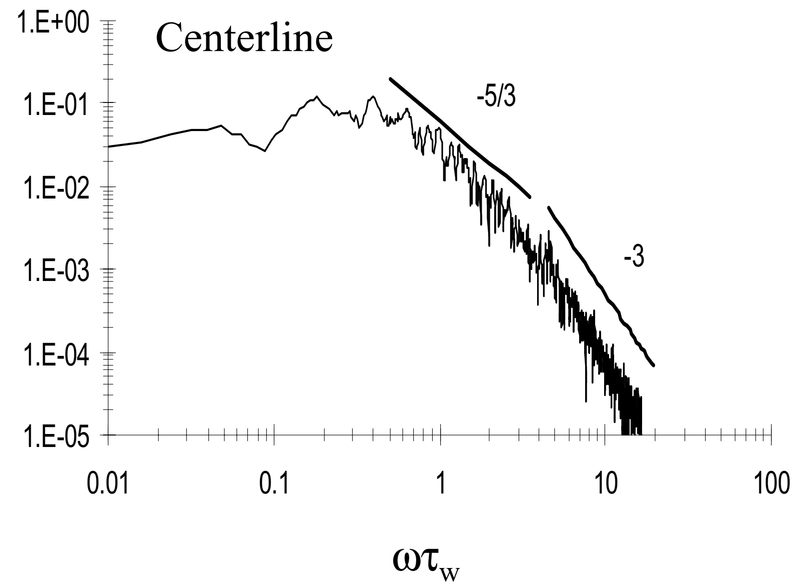

Mean density profile taken with thermocouple measurements, and showing error bars.

# Density fluctuation power spectra

2.4 cm downstream

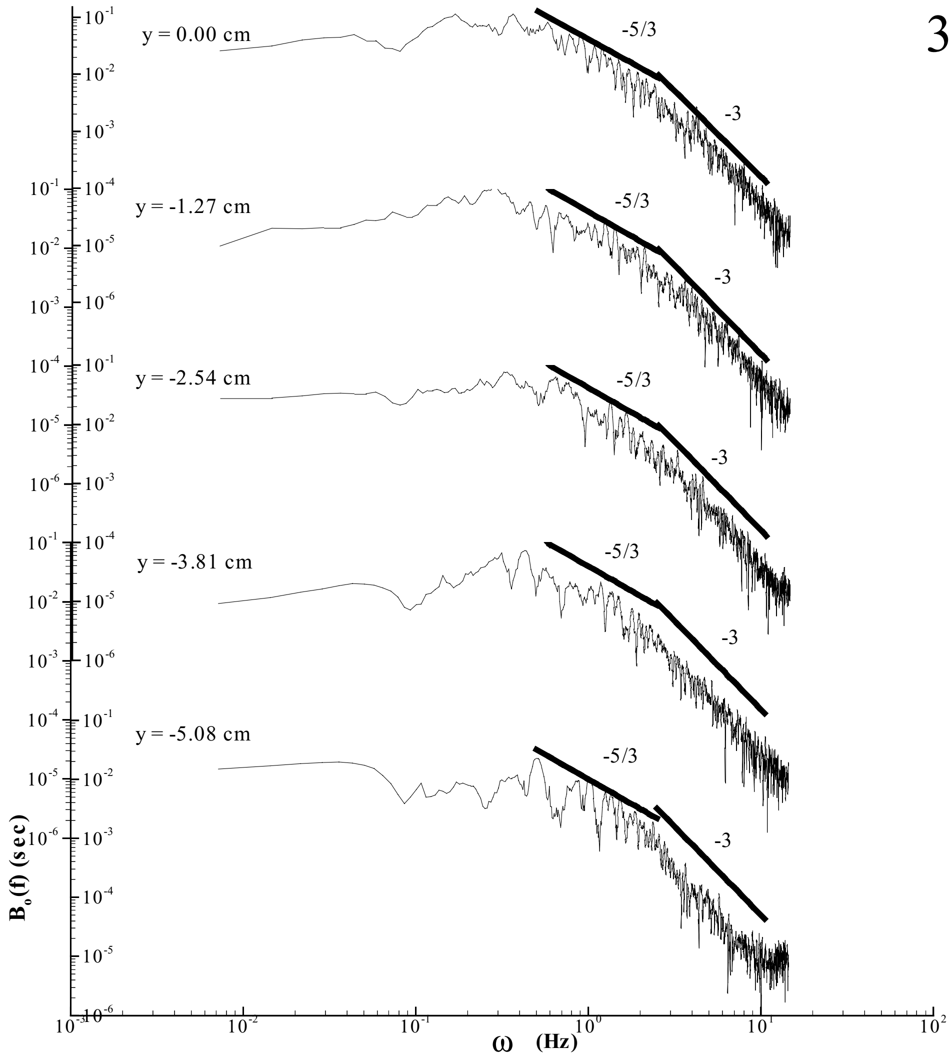



30 cm downstream



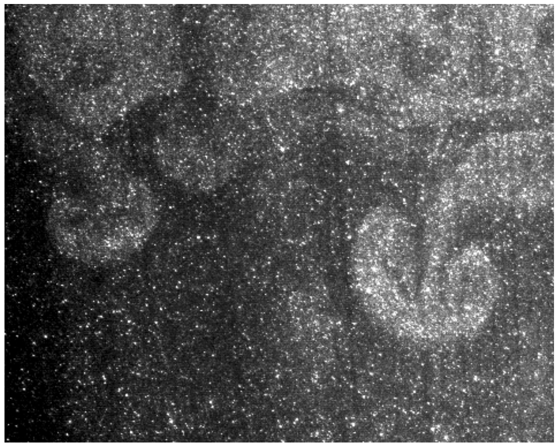
# More power spectra

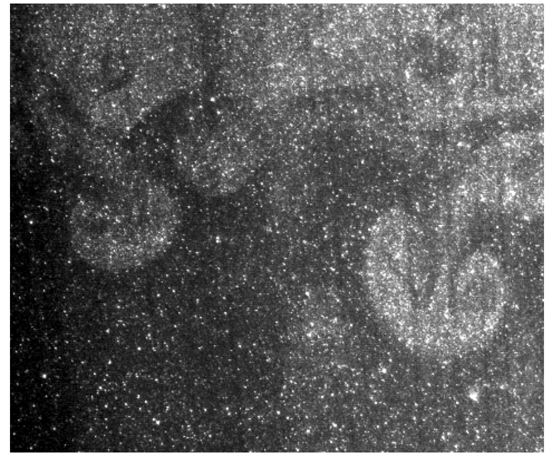
30 cm downstream
Centerline

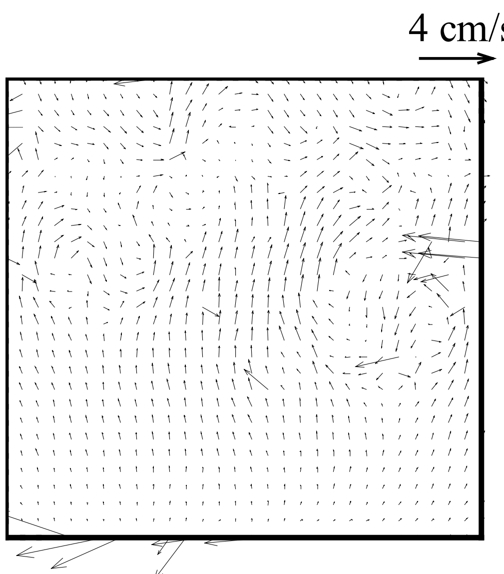


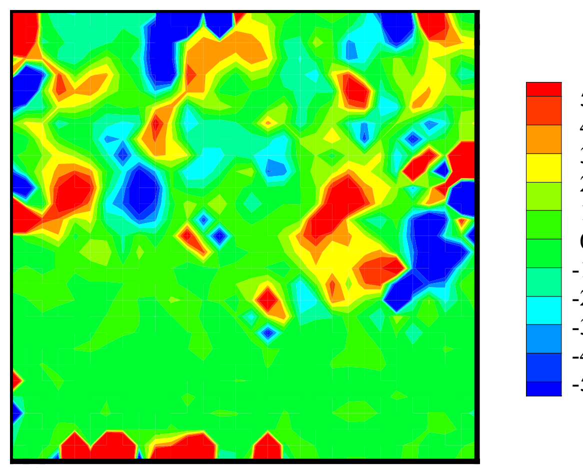

Mix edge

# PIV-S

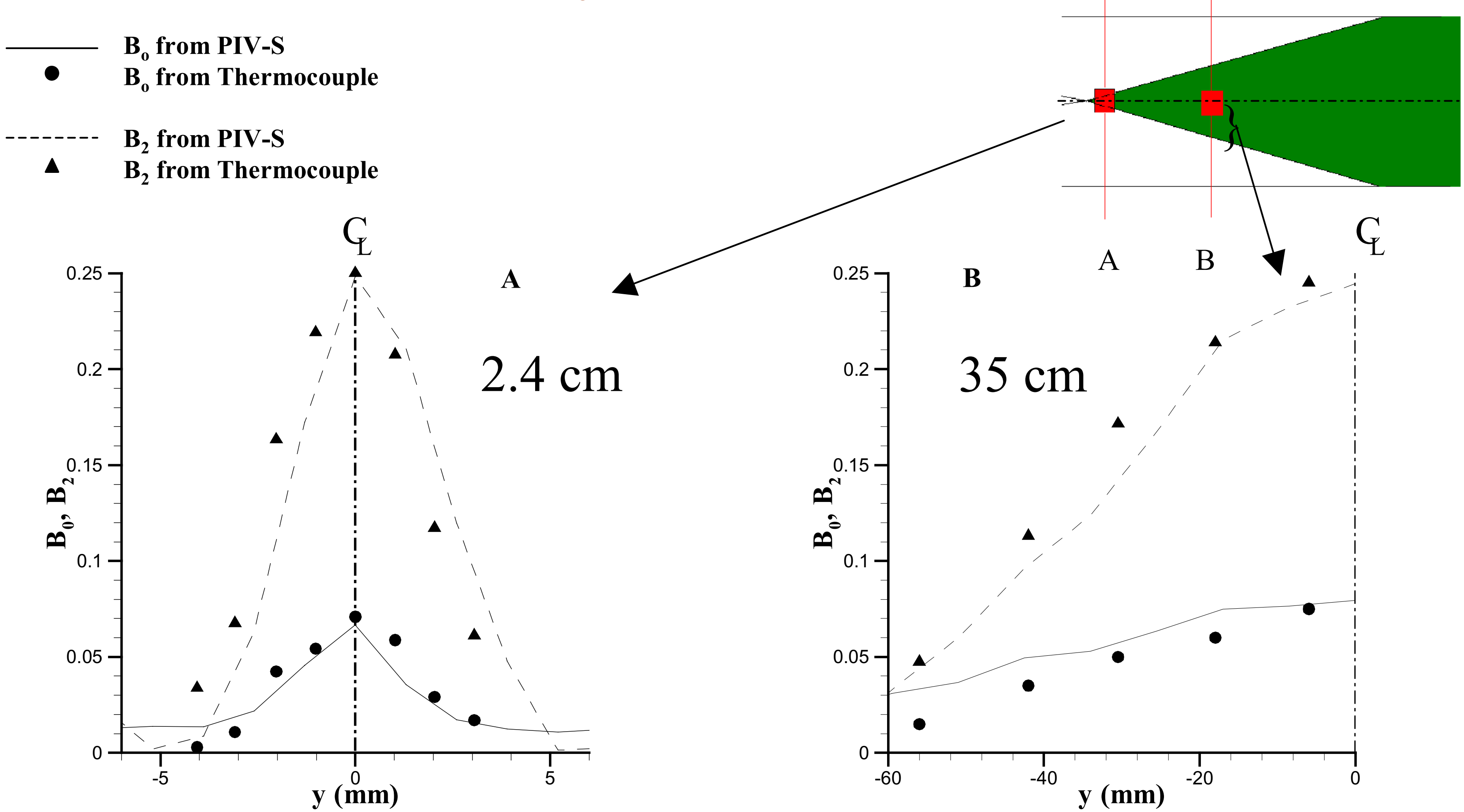




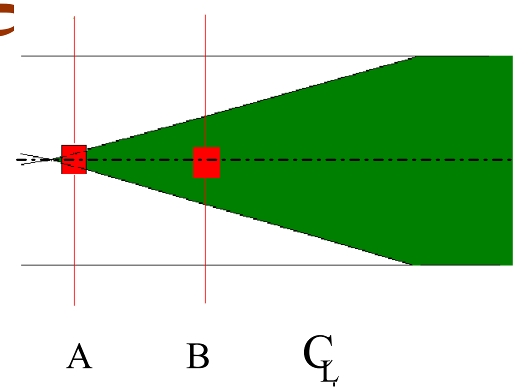


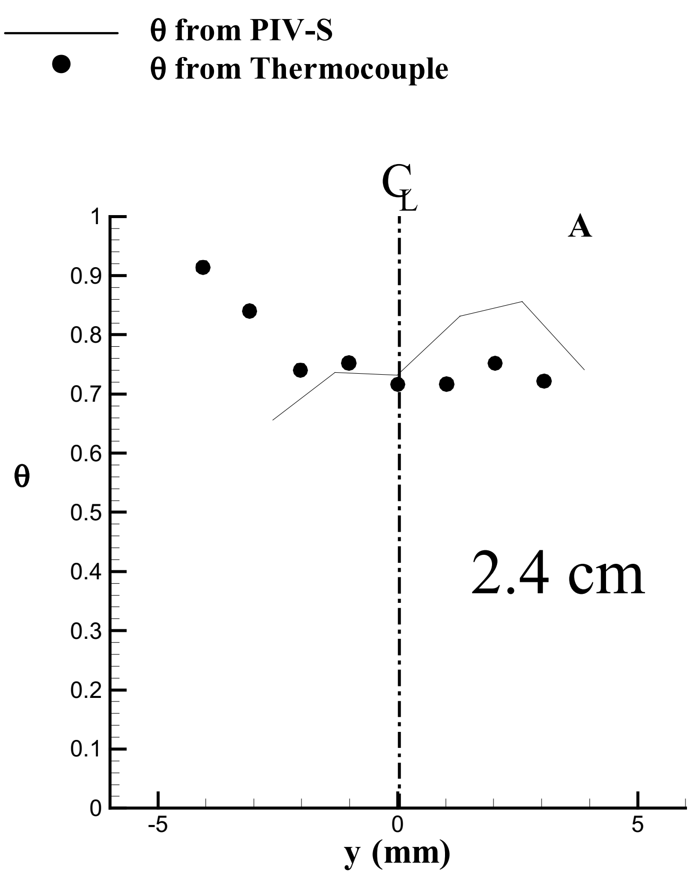



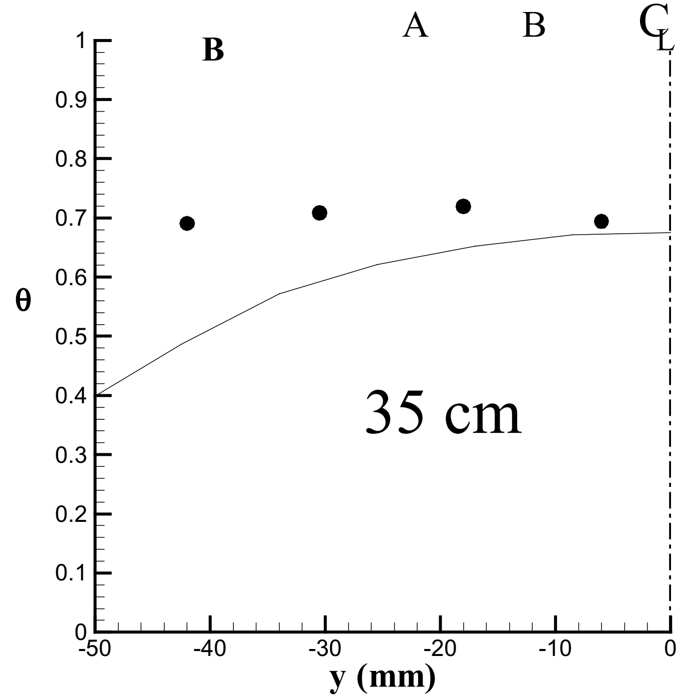
# Density fluctuations



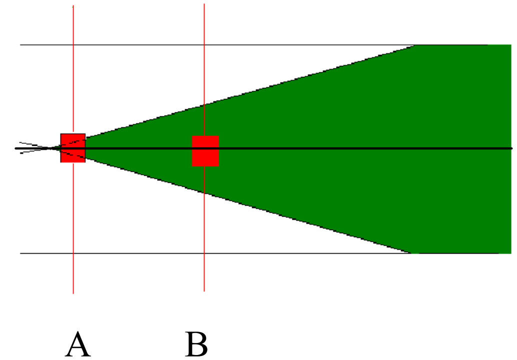
# Molecular Mixing



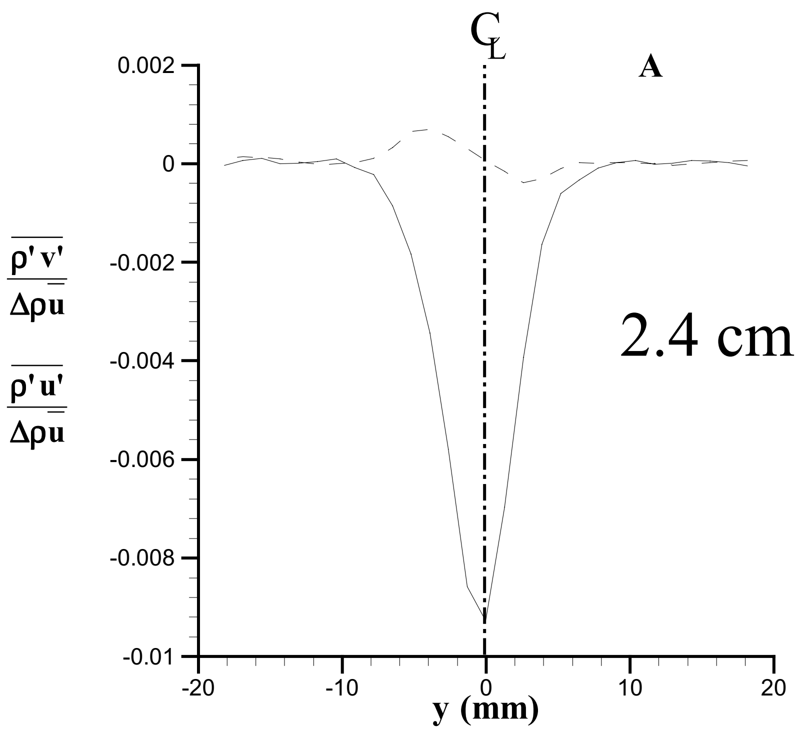



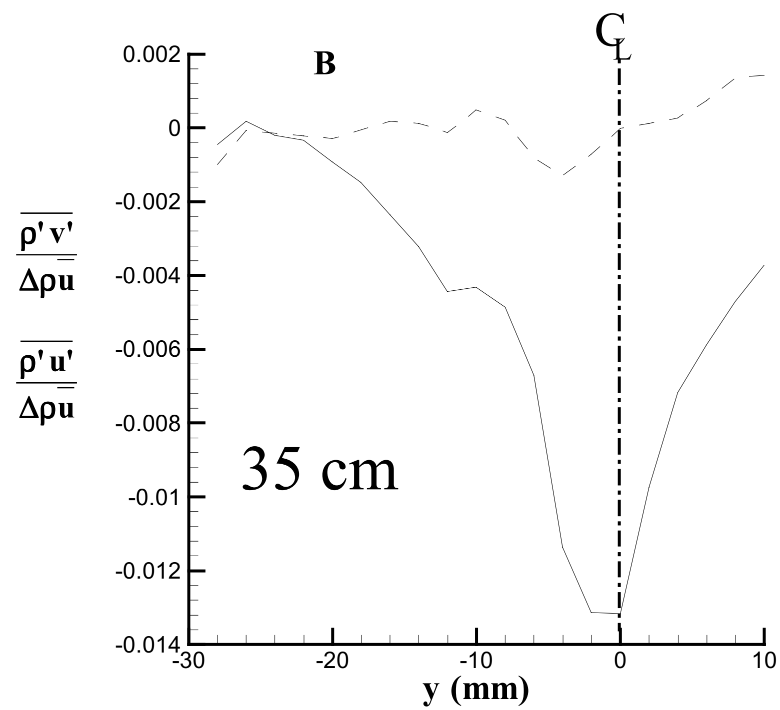
# Density/Velocity Correlations




———— $\frac{\overline{\rho' v'}}{\Delta\rho \bar{\bar{u}}}$

- - - - - - $\frac{\overline{\rho' u'}}{\Delta\rho \bar{\bar{u}}}$



# Scatter plots of velocity fluctuations

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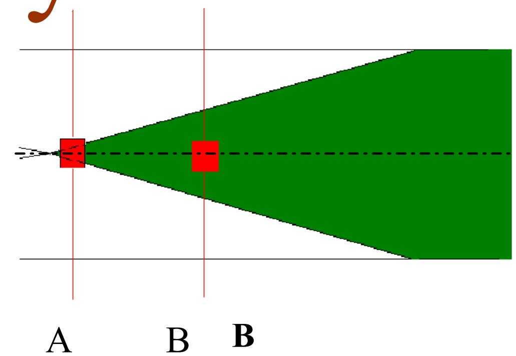
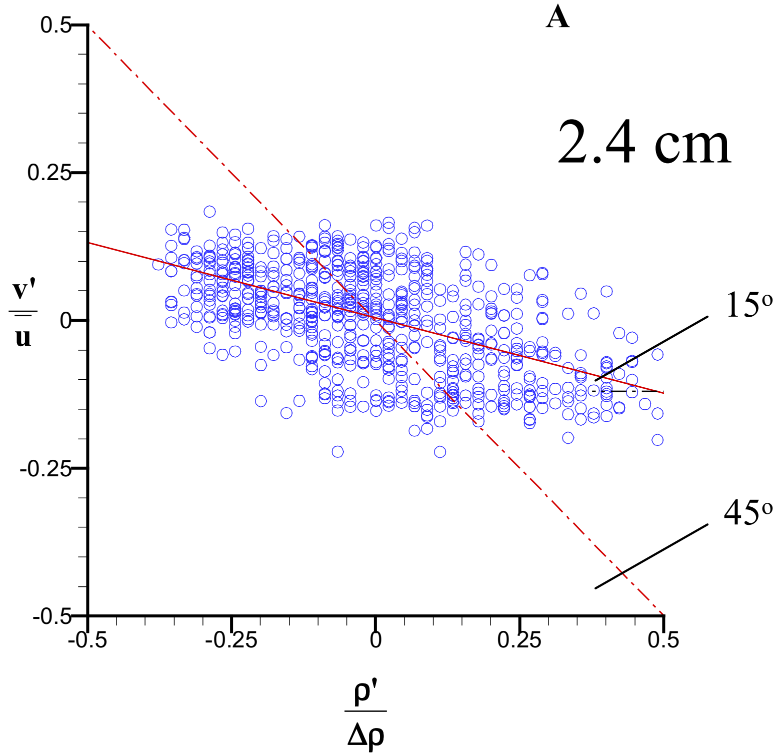
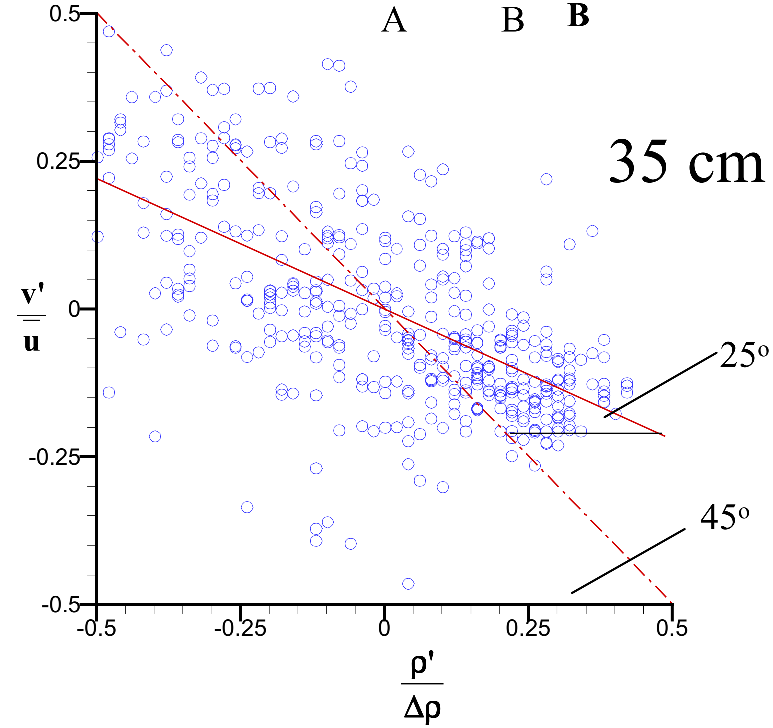



Taken at centerline

**A**




**B**



# Velocity Fluctuations (35 cm)

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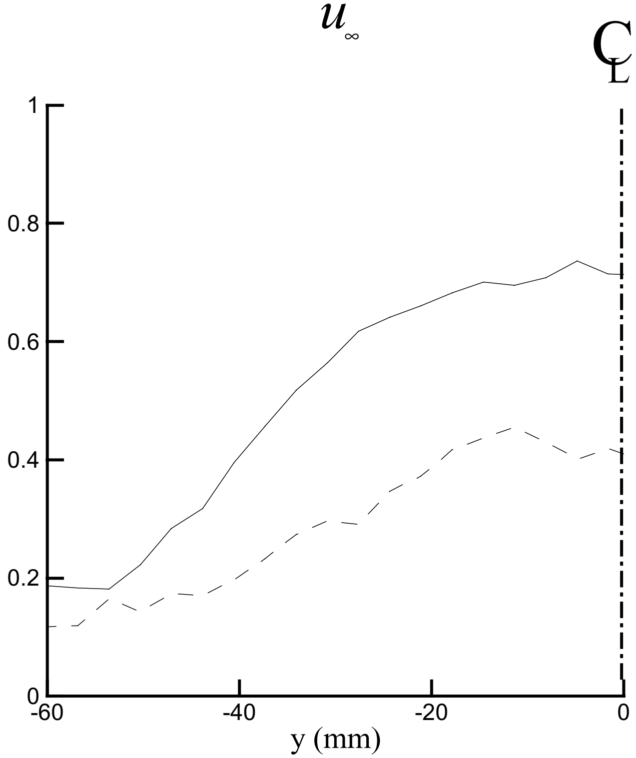
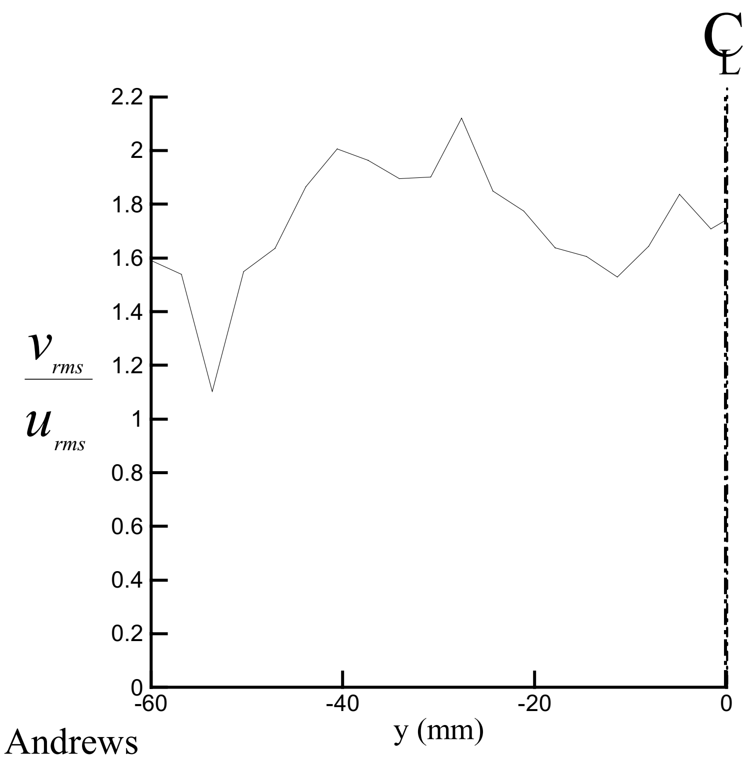
Legend: solid line — $\frac{v_{rms}}{u_\infty}$; dashed line — $\frac{u_{rms}}{u_\infty}$

$$u_\infty = 0.7\sqrt{A_t gH/4}$$



# Anisotropy Tensor

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$$b_{ij} = \frac{< u'_i u'_j >}{< u'_k u'_k >} - \frac{1}{3}\delta_{ij}$$

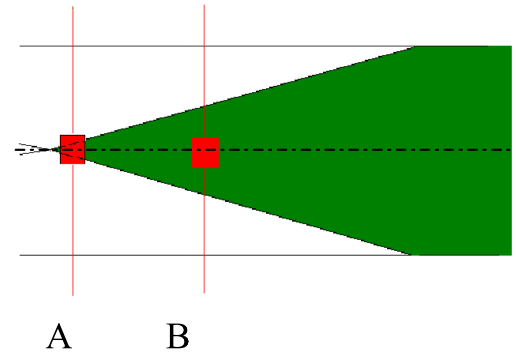
$$< u'_i \, u'_j >= 0 \quad \text{if i} \neq \text{j}$$

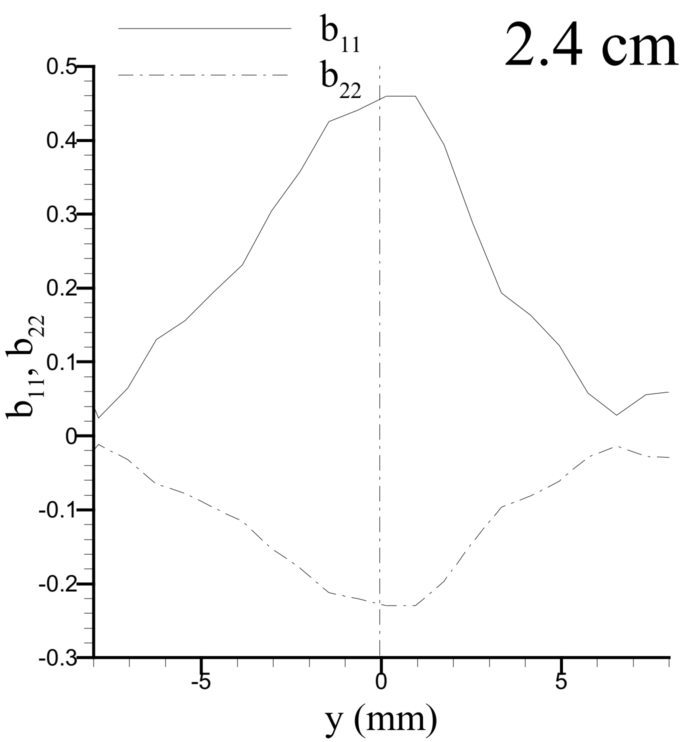
where $$< u'_k \, u'_k >= \overline{u'^2} + \overline{v'^2} + \overline{w'^2}$$

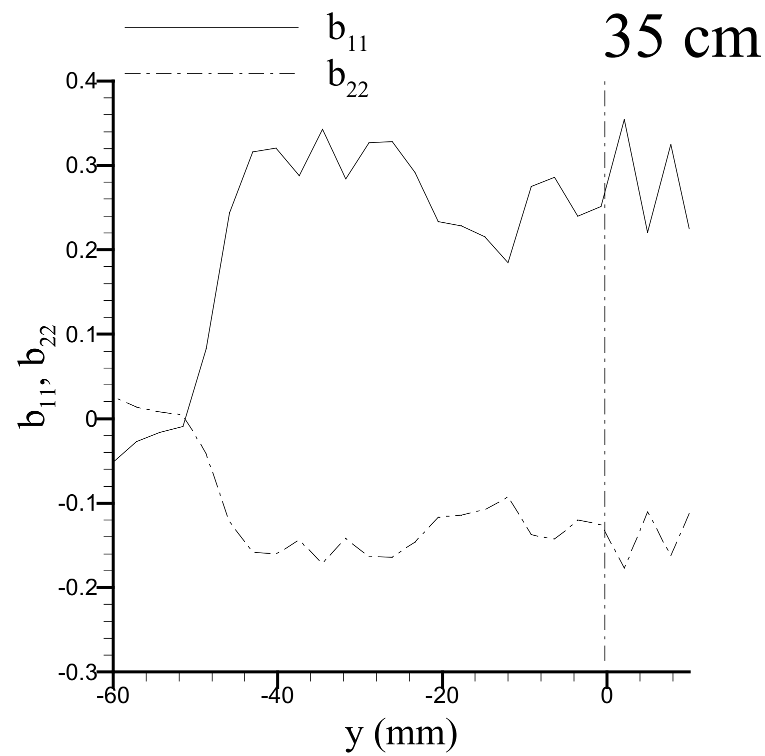
$$\approx 2\overline{u'^2} + \overline{v'^2}$$

Isotropy $\Rightarrow b_{ii} = 0$

# Anisotropy Tensor



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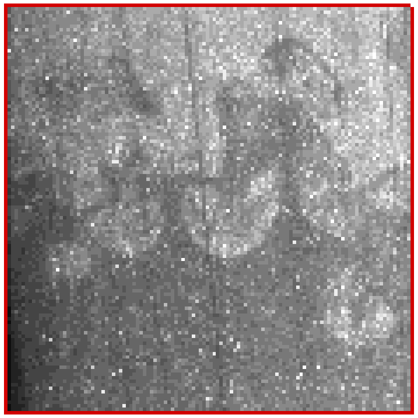
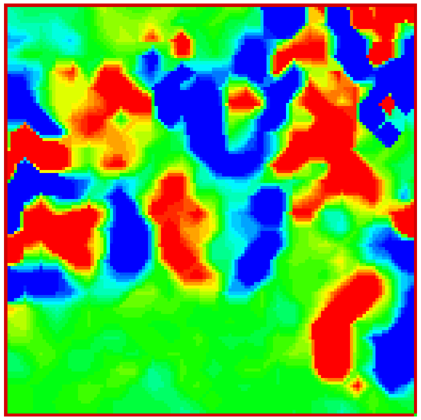
# Future work

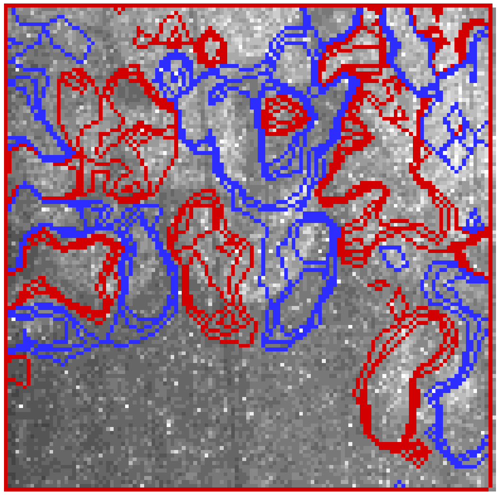
- Buoyancy and shear
- Non-equilibrium strained configurations:
  - Contractions
  - Obstacles
- Modeling
- Large density differences





Photographs

Vorticity



Photographs overlaid with vorticity