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EXPERIMENTAL FLUID DYNAMICS LABORATORY
Department of Mechanical and Aerospace Engineering
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EFFECTS OF SPATIAL ALIGNMENT IN STEREO PARTICLE IMAGE VELOCIMETRY

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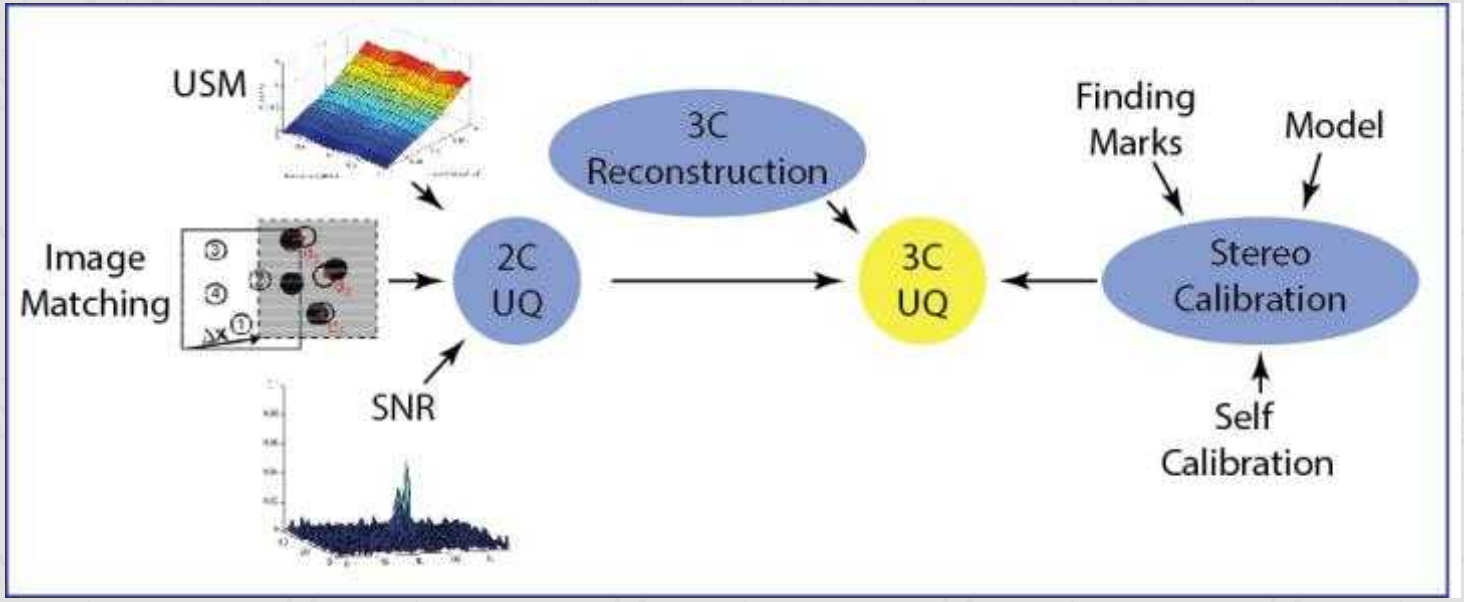
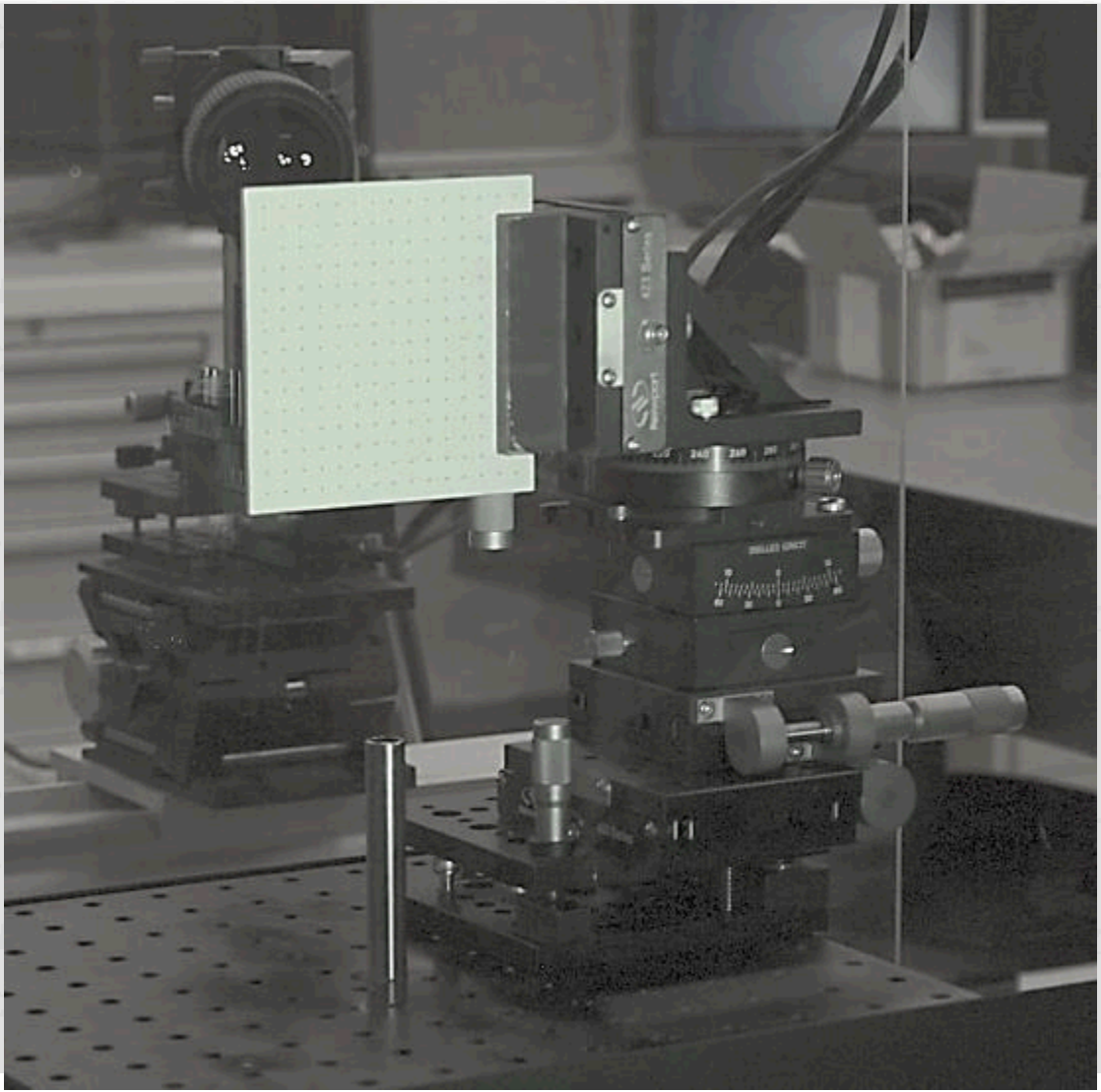
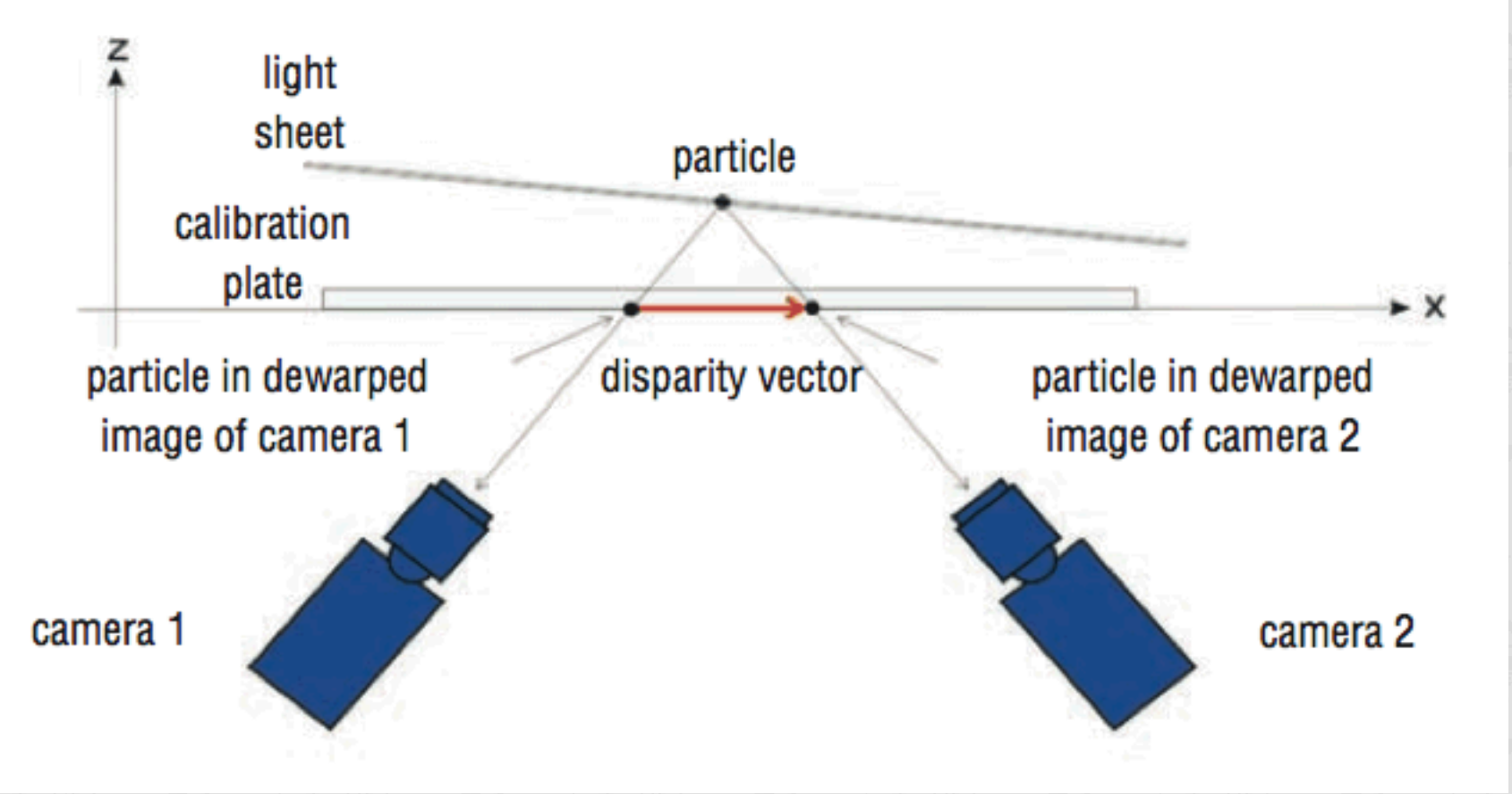
PIV UNCERTAINTY ROADMAP



CALIBRATION



STEREO SELF CALIBRATION



DISPARITY AND SPATIAL ERROR

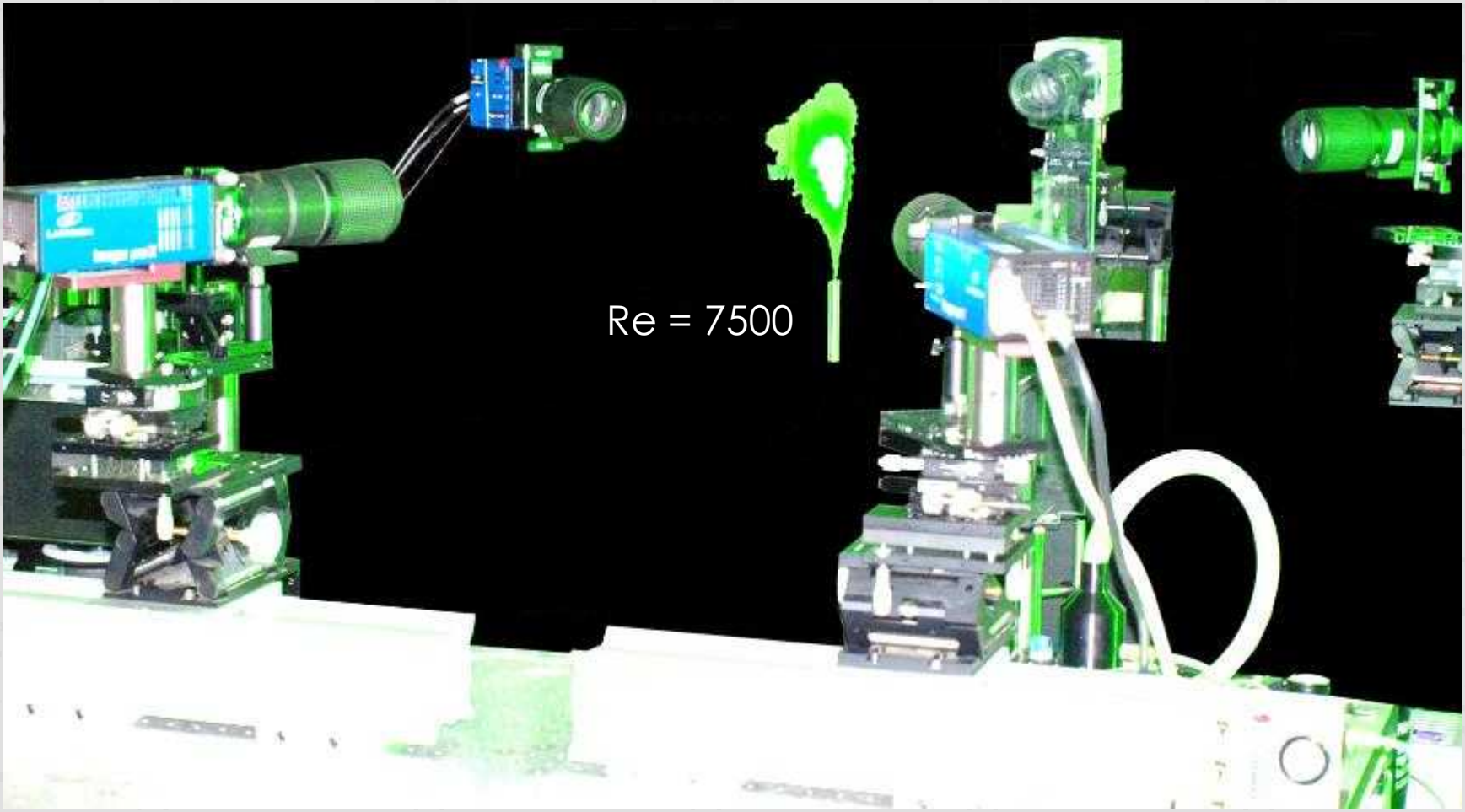
- By Disparity, we mean that each camera in the SPIV system is mapped to a different point in space.
- By Spatial Error, we mean that the SPIV SYSTEM (both cameras) is mapped to the wrong points in space
- The disparity can average to zero spatial error, and one can have spatial error with no disparity, or a combination of both.
- Our method detects both issues.

THE PLAN

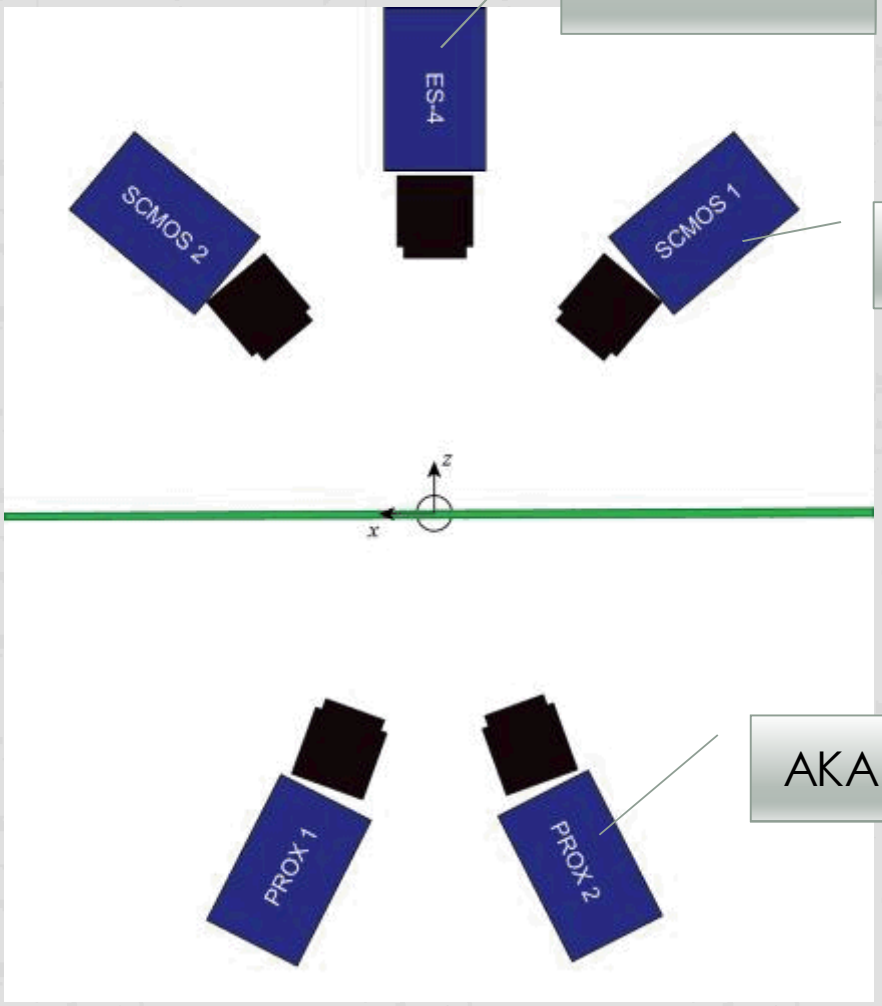
- Investigate Stereo Bias Errors by comparing ***Simultaneous*** Measurements from 3 PIV systems.

- Examine their agreement as a function of
  - Laser Sheet Thickness
  - Camera Angle

SUBMERGED JET SETUP



CAMERA SETUP

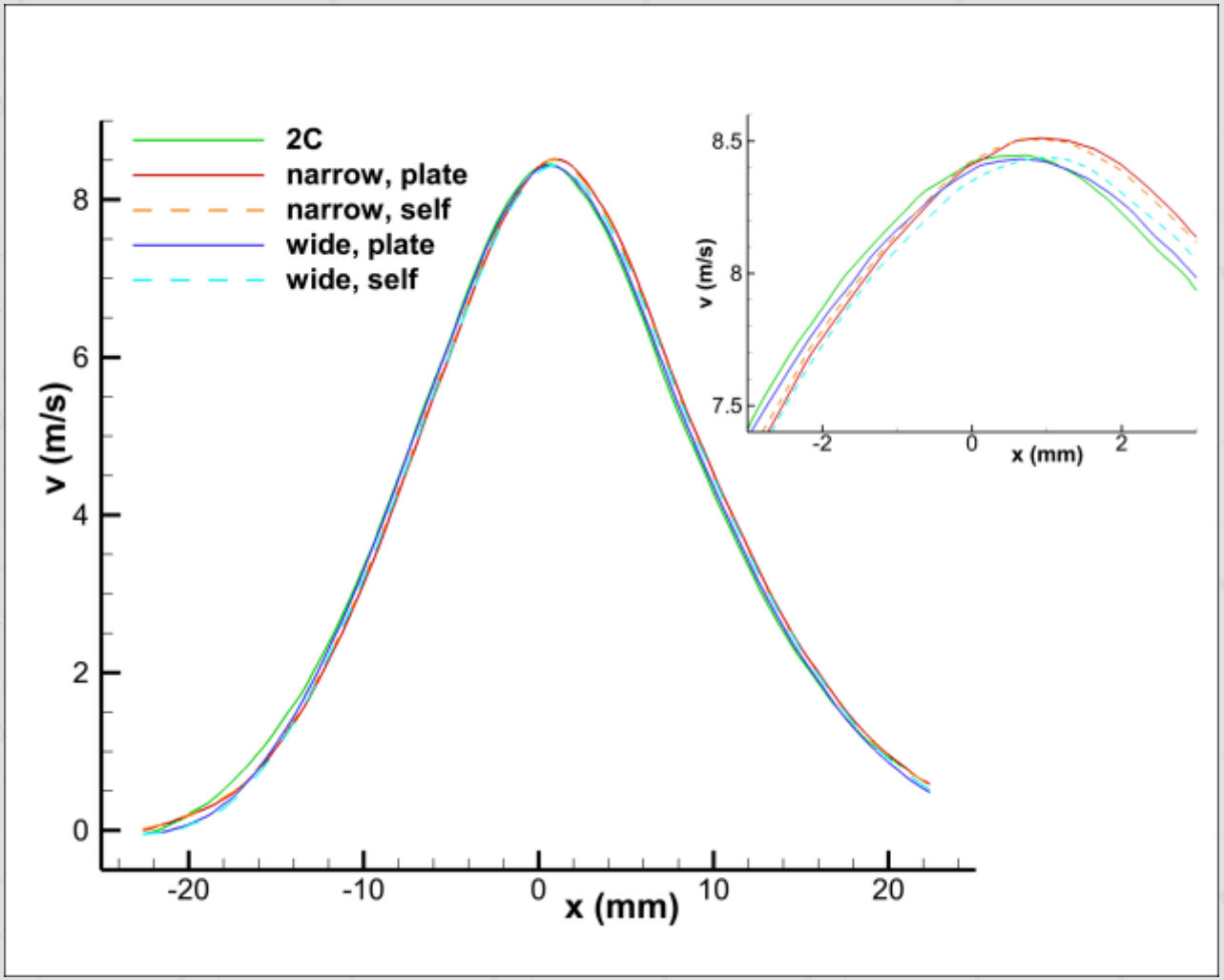


AKA "Truth"

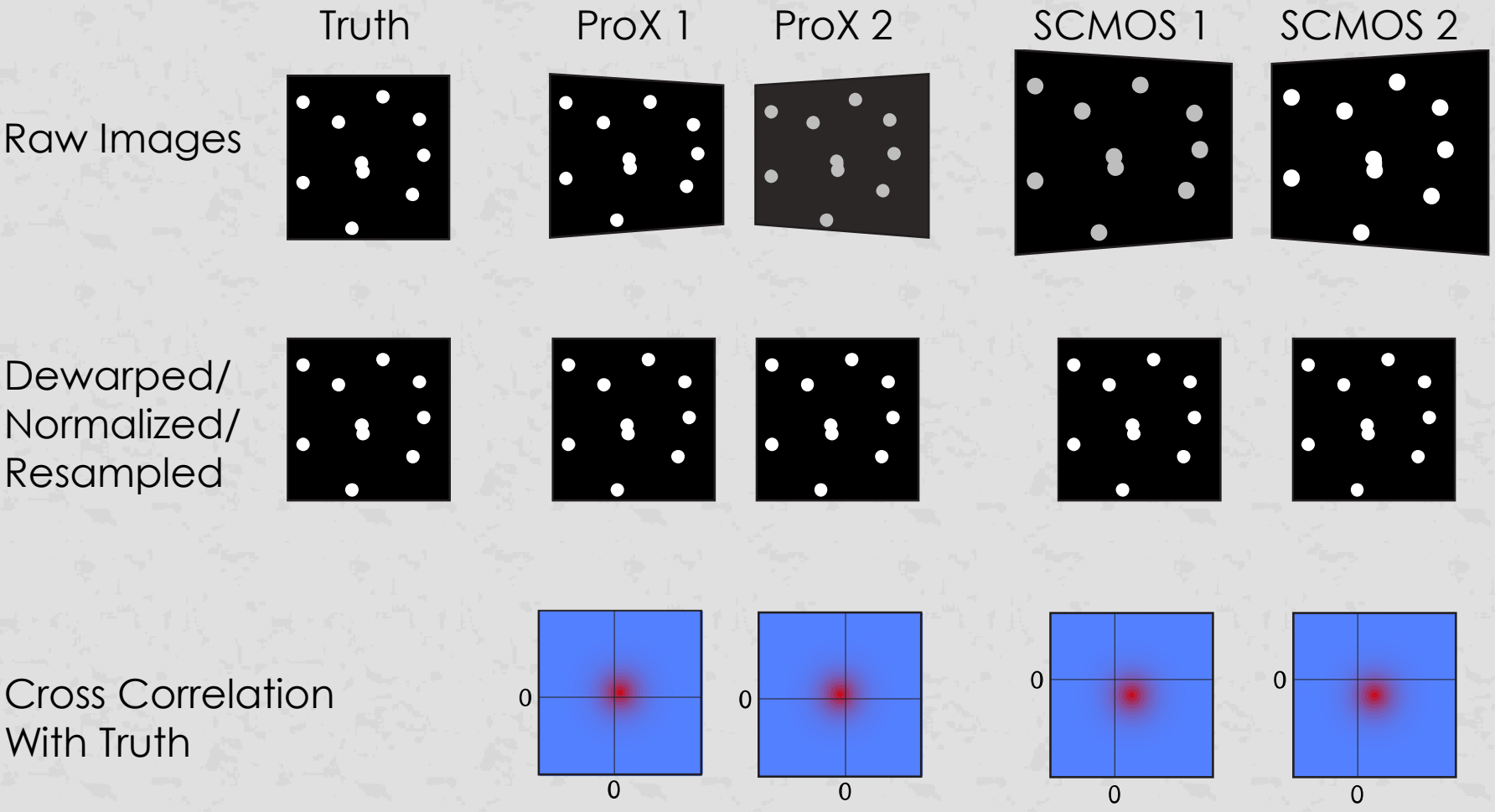
AKA "Wide"

AKA "Narrow"

TIME AVERAGE FLOW

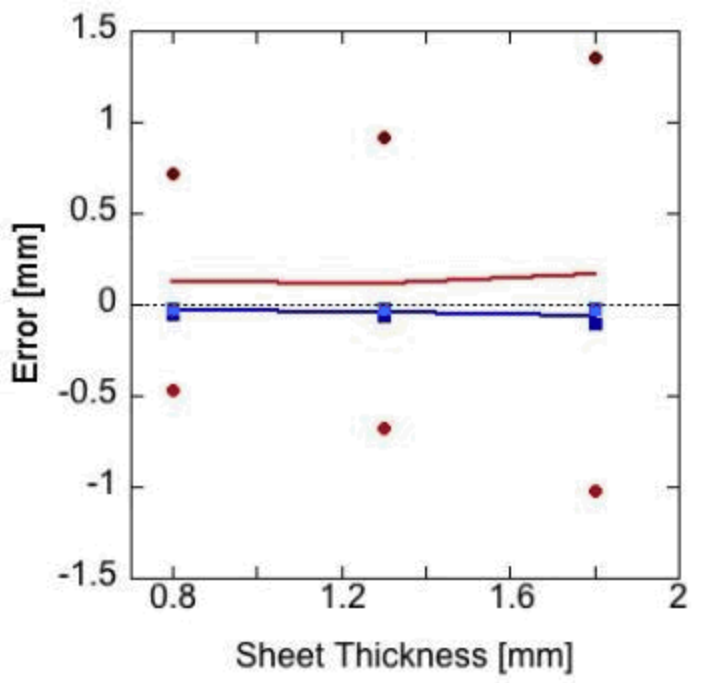


SPATIAL ERROR CODE

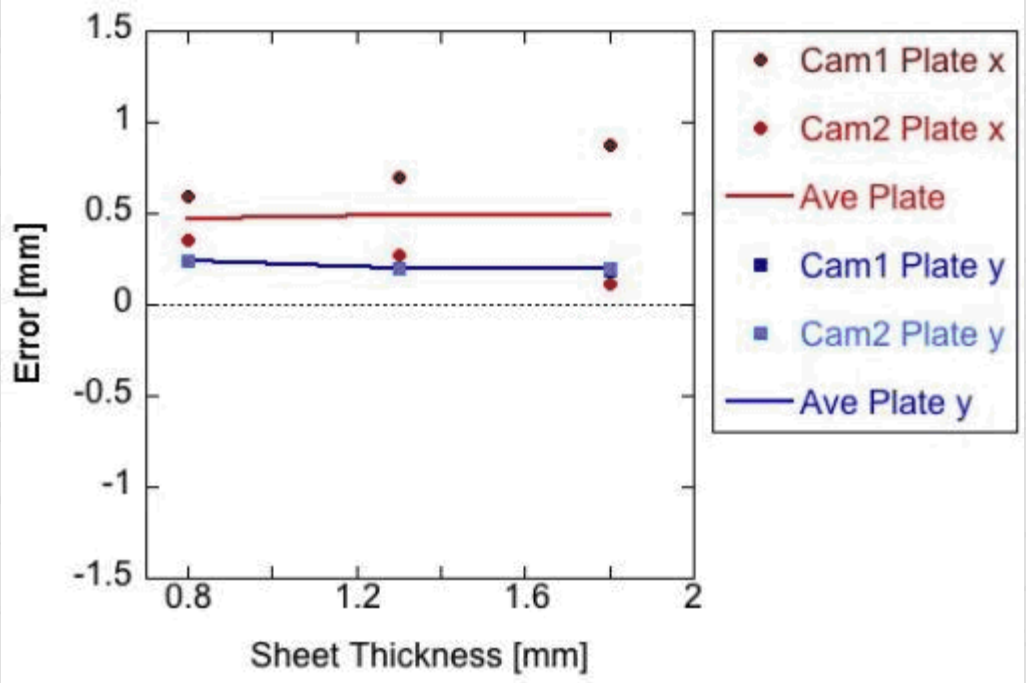


SPATIAL ERROR RESULTS

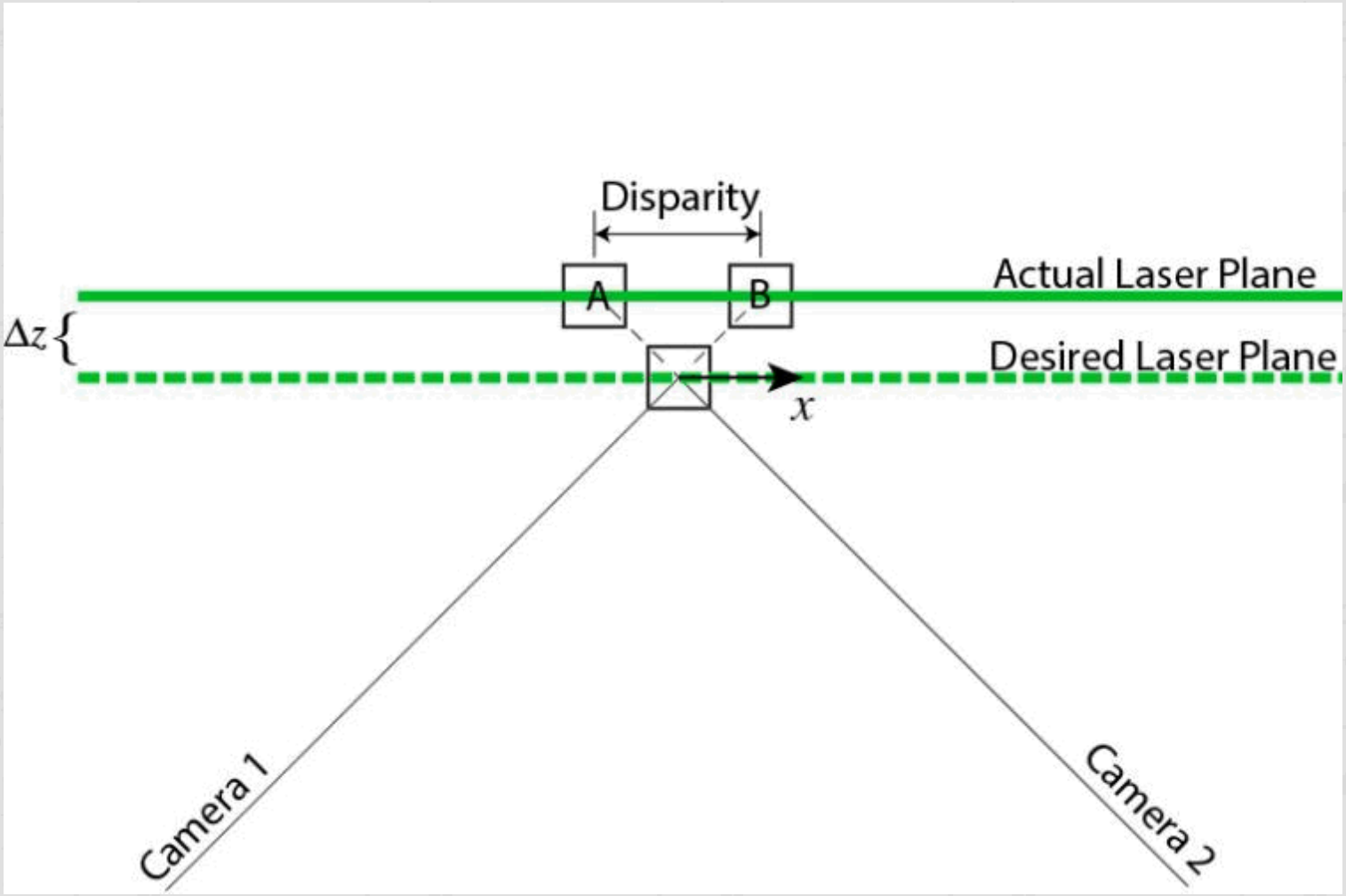
Wide Angle



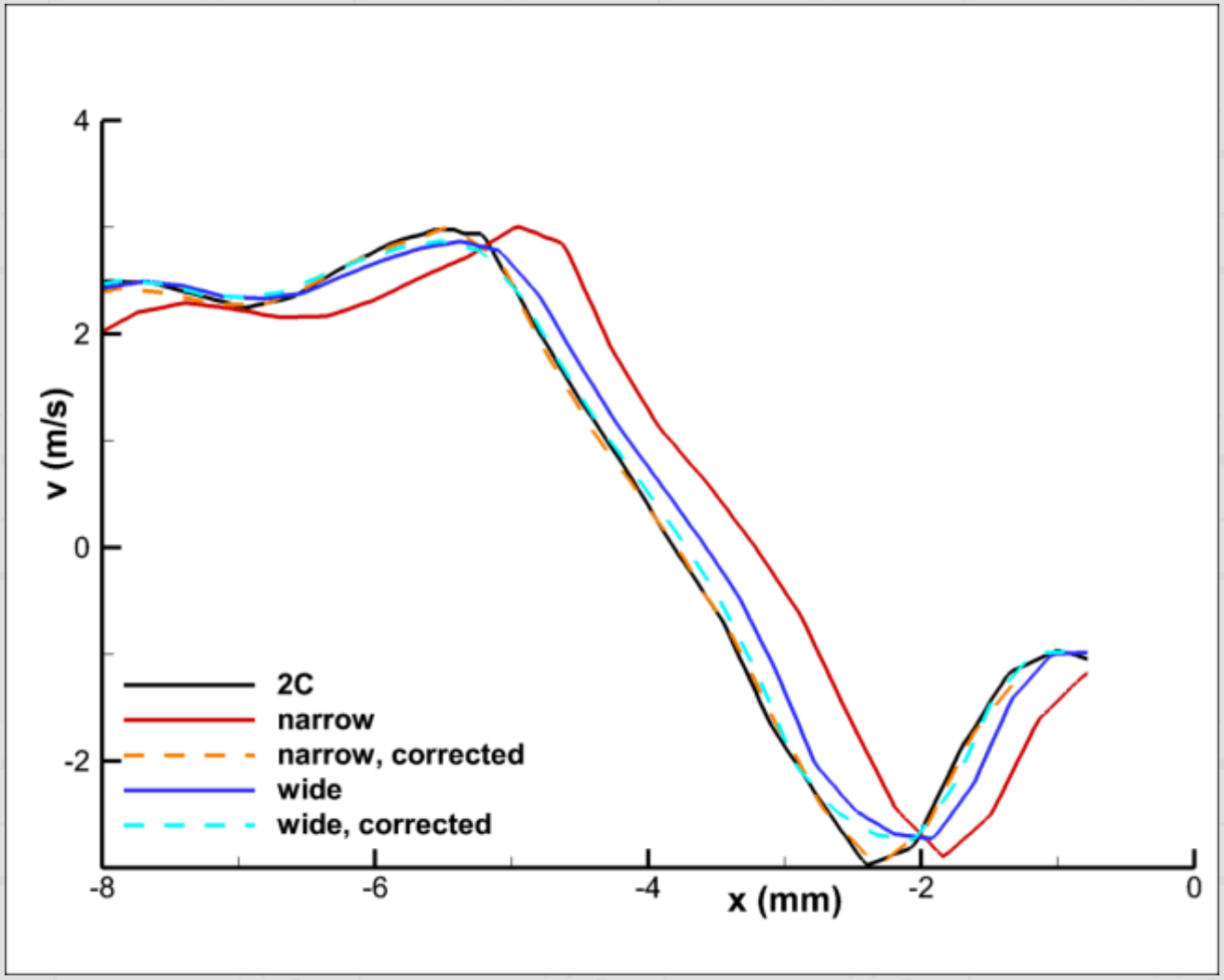
Narrow Angle



LASER SHEET MISALIGNMENT IN z CAUSES x DISPARITY



USING ERROR RESULTS TO CORRECT DATA



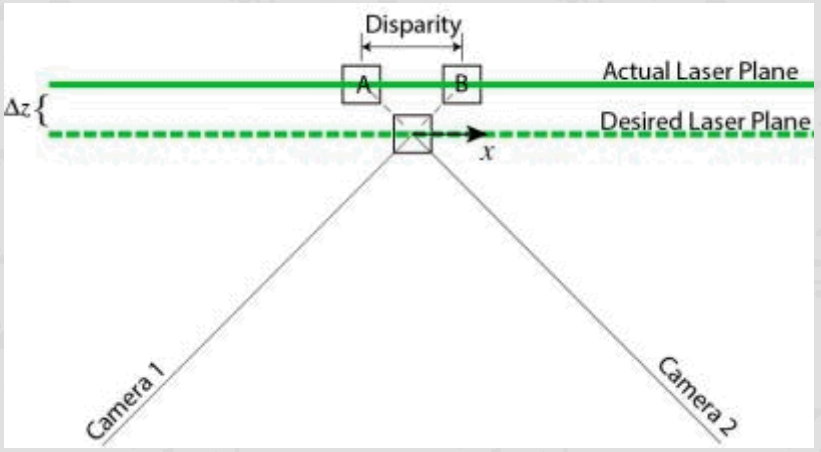
SUCCESSFUL SELF CALIBRATION ELIMINATES DISPARITY

- Just as the vendors say.
- In some cases, (thick laser sheet, extreme camera angles, etc.) self calibration may be unsuccessful and disparity will remain.

IMPACT OF DISPARITY

- For this setup, both cameras are equally sensitive vertical motion.
- The vertical component is thus the average of the vertical vector computed from the image pairs of each camera.
- Disparity results in the two vectors in the average being located at different locations:

$$V_i = \frac{1}{2}\left(V_{A_i} + V_{B_i}\right)$$



IMPACT OF DISPARITY ON REYNOLDS STRESSES

$$\overline{v'v'} = \frac{1}{N-1}\sum_{i=1}^{N}\left[\frac{1}{2}\left(V_{A_i} + V_{B_i}\right)\right]^2$$

$$= \frac{1}{N-1}\sum_{i=1}^{N}\frac{1}{4}\left(V_{A_i}^2 + V_{B_i}^2 + 2V_{A_i}V_{B_i}\right)$$

$$= \frac{1}{4}\left(\sigma_{V_A}^2 + \sigma_{V_B}^2 + 2\sigma_{V_AV_B}^2\right)$$

$$= \frac{1}{4}\left(2\sigma_{V_A}^2 + 2\rho\sigma_{V_A}^2\right)$$

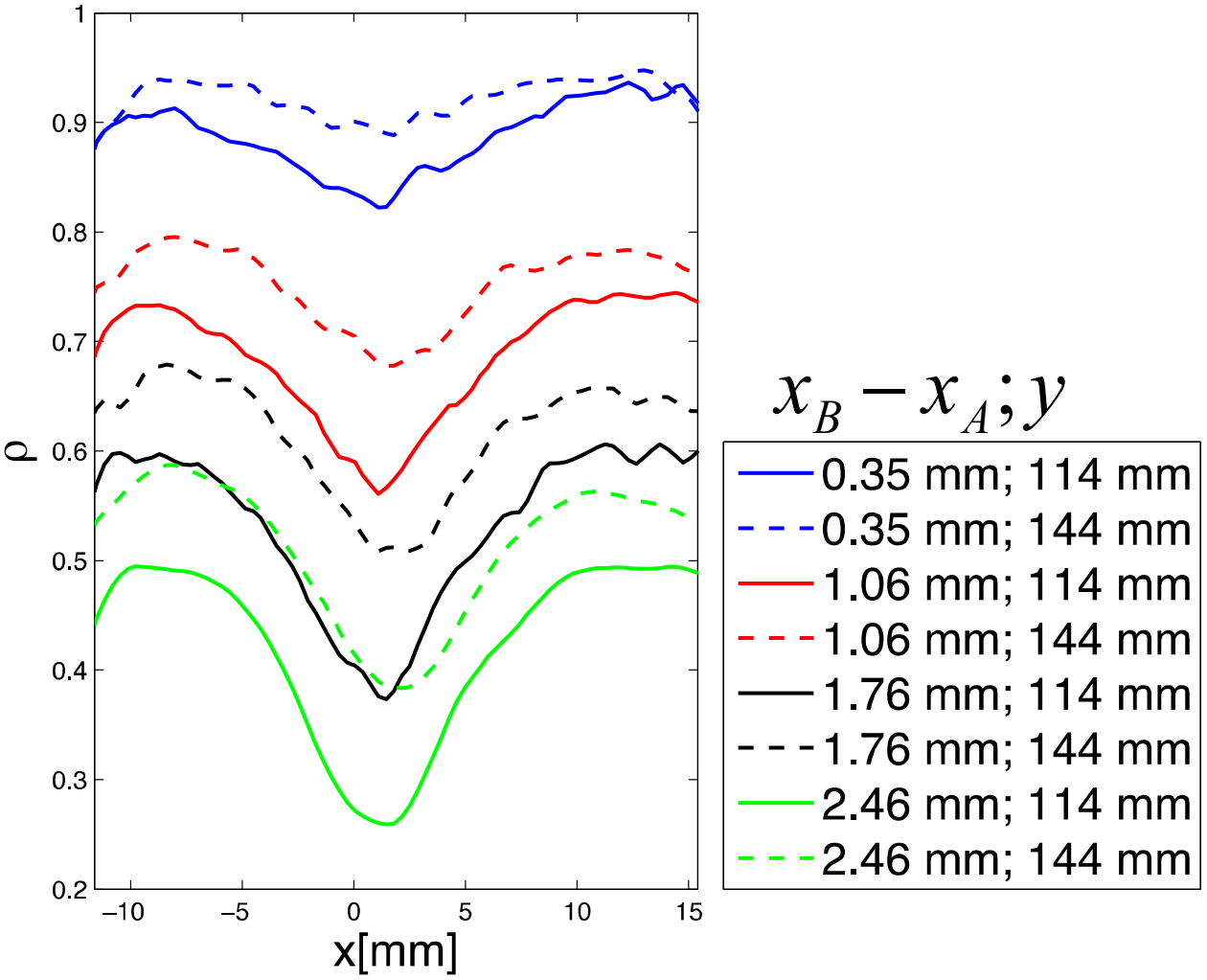
$$\overline{v'v'} = \frac{\sigma_{V_A}^2}{2}\left(1+\rho\right)$$

$$\rho = \frac{\sigma_{V_AV_B}^2}{\sigma_{V_A}\sigma_{V_B}}$$

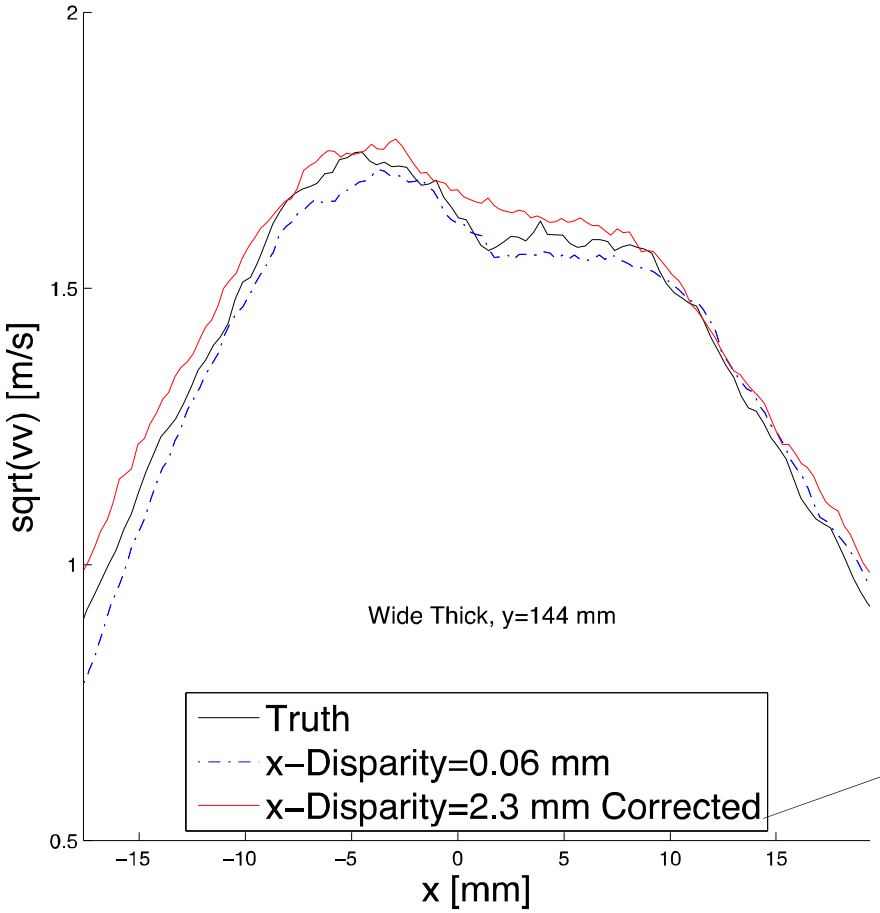
For a given flow, ρ is a function of space and the vector distance between A and B.

$-1 < \rho < 1$

ρ FOR OUR JET



IMPACT OF DISPARITY ON REYNOLDS STRESSES



$$* \frac{2\overline{v'v'}}{(1+\rho)}$$

CONCLUSIONS

- Stereo PIV calibration can lead to:
  - Disparity
  - Spatial Error
- An accurate measurement of spatial error on each camera can be found using an independent image of the laser sheet acquired by a camera normal to the sheet.
- Disparity can "filter" fluctuations and smooth means.
- The extent to which turbulent fluctuations are suppressed by disparity is a function of the velocity covariance over the disparity distance.
- In ideal cases, self-calibration eliminates disparity, but changes the origin. For our data, changes are on the order of 1% of the field of view.
- Relatively small (1%) spatial error in the presence of gradients can cause velocity errors to appear large.

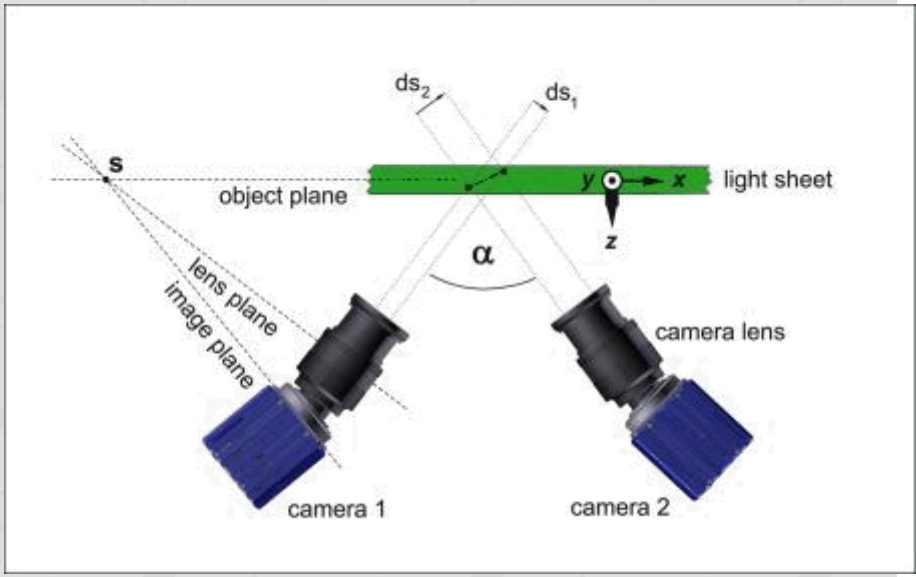
QUESTIONS?

MOTIVATION

- PIV has become the dominant laboratory fluid velocity measurement technique.
- The uncertainty of PIV measurements has only recently received interest.
- Thus far, 3 methods have emerged for finding the random uncertainty associate with vector computation.
- In addition, methods for propagating instantaneous uncertainties into turbulent quantities have been developed.
- Stereo PIV likely has significant calibration bias which is, as yet, unquantified.

STEREO PIV

- Calibration information is used to "Dewarp" the image pairs of each camera to resemble how it would appear if viewed from 90°.
- 2C Processing is performed on each image pair generating 2 components of velocity for each on different coordinate systems. These 4 data are combined to form a 3C vector for each location in the field.



Graphic from LaVision

CROSS STREAM VELOCITY