Optical Measurement Techniques

ME637 -Particle Transport, Deposition and Removal II

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Why Make Measurements?

- Turbulent flows are the rule, not the exception.
- Practical turbulent flows are VERY difficult to simulate using DNS.
- Verification of turbulent flow models.

Optical Techniques: Advantages

- Non-intrusive (seed, but no probes in the flow field)
- Robust (no particle collection on probe)
- High accuracy (accuracy is predictable)
- High precision (Very little drift)
- Small measurement volume

Optical Techniques: Disadvantages

- Expensive!!
- Fragile optics.
- Seeding... Seeding... Seeding...

What Are My Options and Who Sells Them?

- DANTEC -- LDA, PDA, PIV, PLIF, IPI
- TSI -- LDA, PDA, PIV
- VioSense -- LDA, Shear Stress, PIV
- LAVision -- PIV, PLIF, IPI

How do LDA & PDA Systems Work?

- A pair of coherent laser beams intersect, forming a fringe pattern in the measurement volume.
- As a seed particle passes through the fringe pattern, the light reflected from the particle pulsates.
- The pulsating light is measured by a photodetector.
- The frequency of the pulsating light and the fringe spacing is used to compute a velocity.

LDA: u = d/t

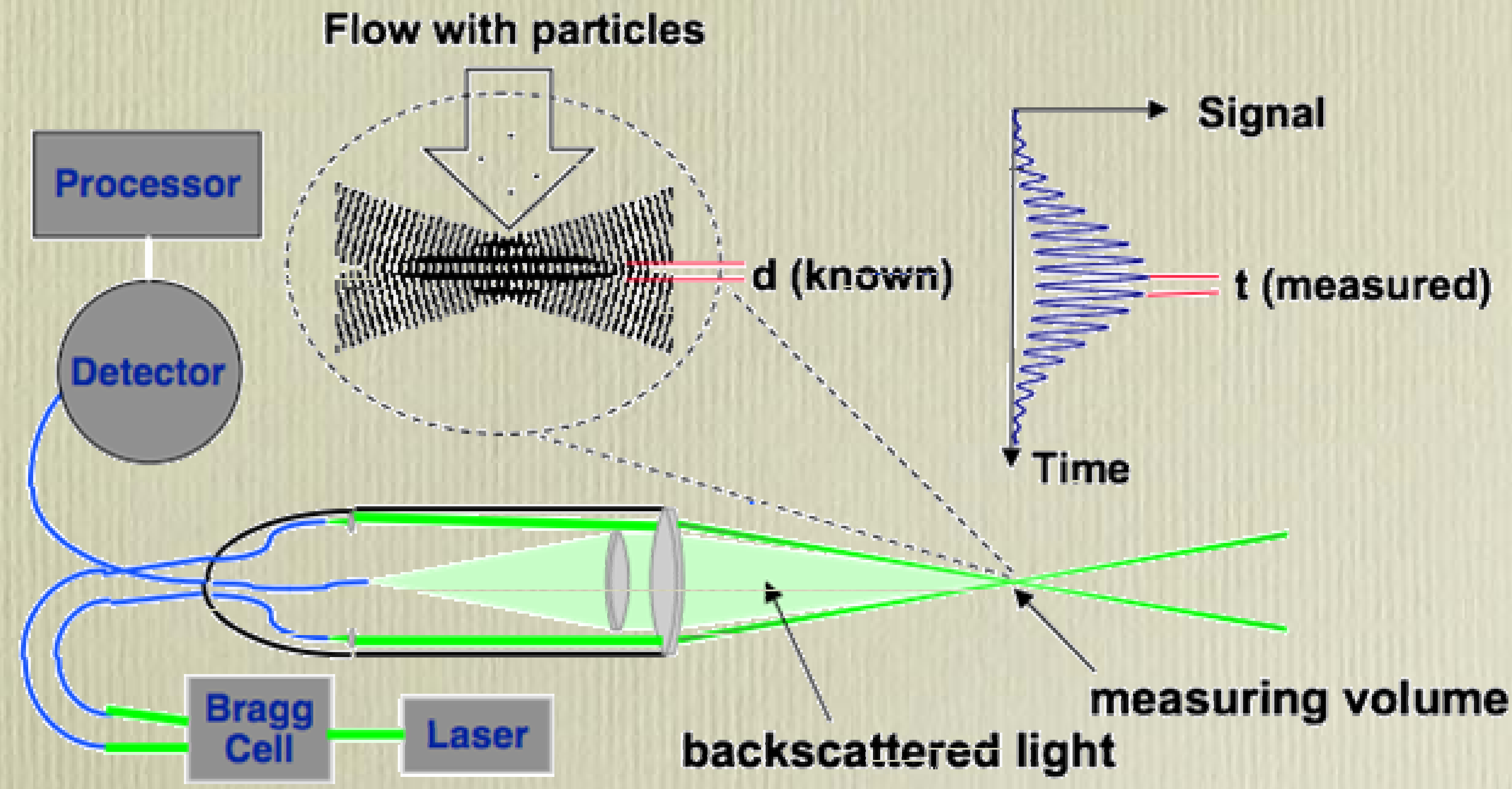


Figure courtesy of DANTEC Measurement Technology

LDA: Equations

Fringe Spacing

$$\delta_f = \frac{\lambda}{2\sin(\frac{\theta}{2})}$$

Frequency of Pulse

$$I(f) = \frac{1}{T}\int_{-\infty}^{\infty} I(t)e^{-i2\pi ft}dt$$

Velocity

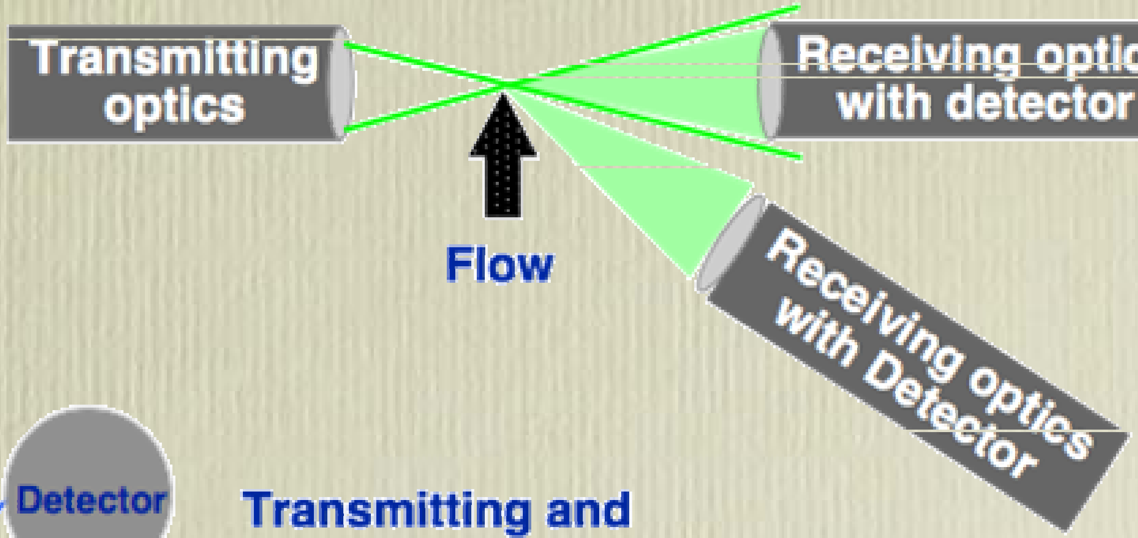
$$u = f_{max(I)}\delta_f = \frac{f_{max(I)}\lambda}{2\sin(\frac{\theta}{2})}$$

LDA: System Configurations

Forward Scatter

Difficult to align

Lower power requirements



Back Scatter

Fiber optic LDA systems make alignment a non-issue

Larger power requirements

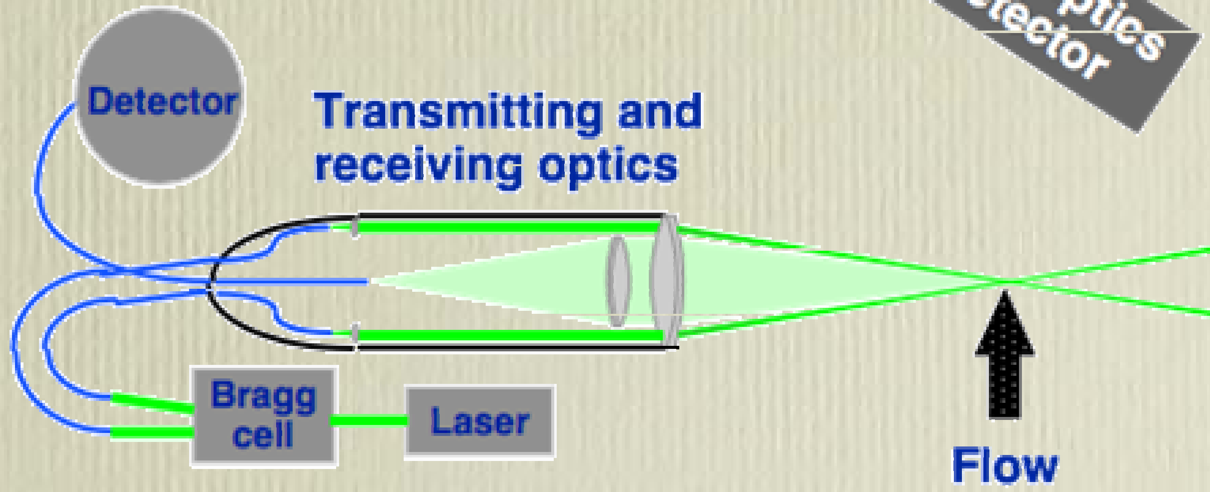


Figure courtesy of DANTEC Measurement Technology

LDA: Directional Ambiguity

- Particles moving forward or backwards will produce a pulsating wave with identical frequencies.
- An accousto-optical modulator (Bragg Cell) can be used to oscillate the fringes in the measurement volume.
- Velocity is calculated by subtracting the modulator frequency from the measured frequency.

LDA: Multiple Components of Velocity?

- A different color, λ, is used for measuring each velocity component.
  - Each beam is then separated into three colors:
    green: λ = 514.5 nm
    blue: λ = 488 nm
    purple: λ = 476.5 nm
- A single probe can be used for 2 components
- A second probe is necessary for 3 components

LDA: Seed Particles

Particle Frequency Response

$$\frac{d}{dt}U_p = -18\frac{\nu}{d_p^2}\frac{U_p - U_f}{\rho_p/\rho_f}$$

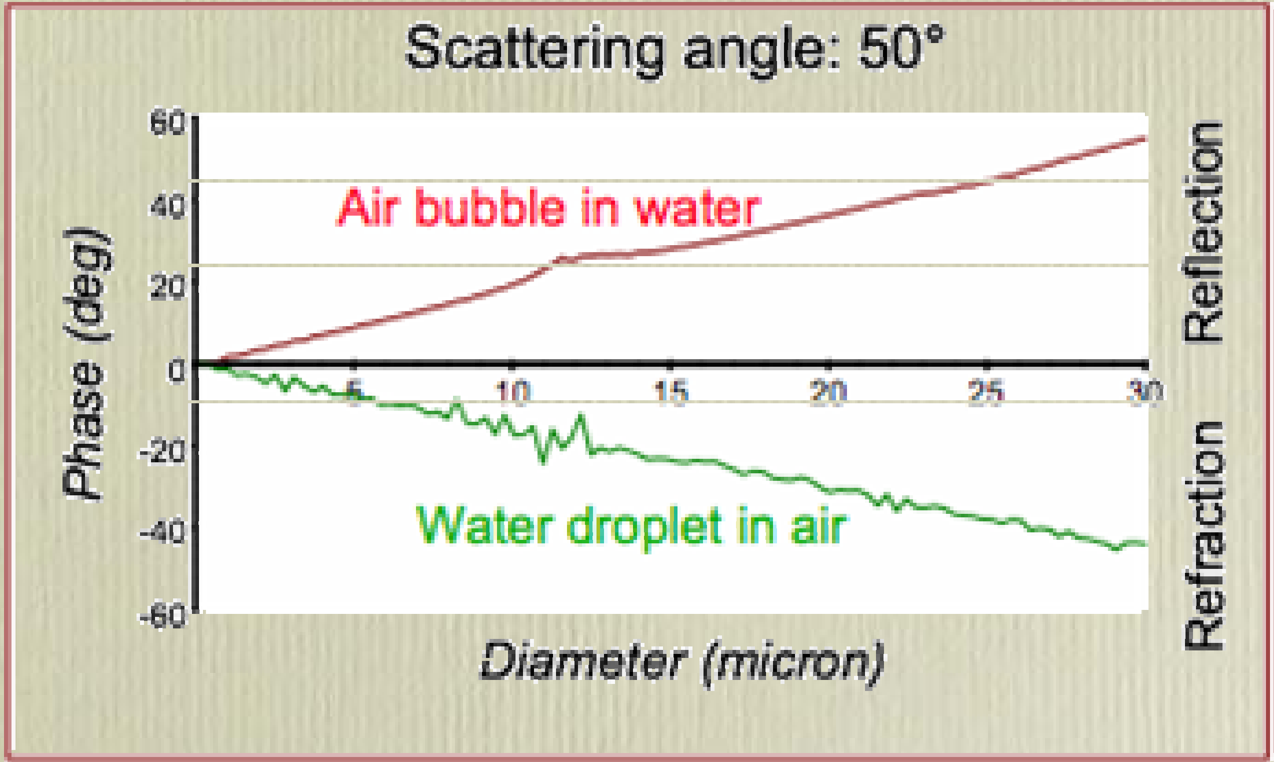
Particle	Fluid	Diameter (μm)	
		f = 1 kHz	f = 10 kHz
Silicone oil	atmospheric air	2.6	0.8
TiO_2	atmospheric air	1.3	0.4
MgO	methane-air flame (1800 K)	2.6	0.8
TiO_2	oxygen plasma (2800 K)	3.2	0.8

Table courtesy of DANTEC Measurement Technology

Phase Dopper Anemometry

- A particle scatters light from two incident laser beams
- Both scattered waves interfere in space and create a beat signal with a frequency which is proportional to the velocity of the particle
- Two detectors receive this signal with different phases
- The phase shift between these two signals is proportional to the diameter of the particle

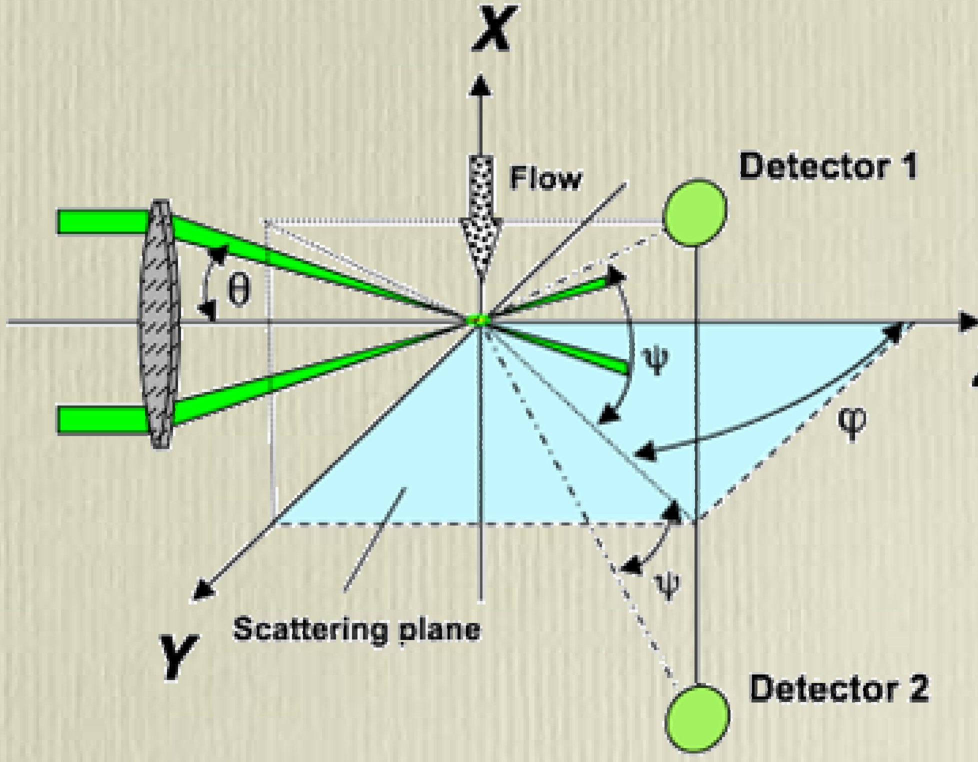
PDA: Phase - Diameter Relationship



$$Phase = -\tan^{-1}\left(\frac{Im[I(f)]}{Re[I(f)]}\right)$$

PDA: General Set-up

- Beam intersection angle θ
- Scattering angle φ
- Elevation angle ψ
- Polarization
  (parallel or perpendicular to scattering plane)
- Shape and size of detector aperture



How does PIV Work?

- Seed particles are uniformed dispersed throughout a flow.
- Two images are acquired, separated by a short period of time, t.
- Spatial correlation between image pair is used to determine a shift, s, in the particle locations.
- Velocity is computed as, v = s/t

PIV: System Configuration

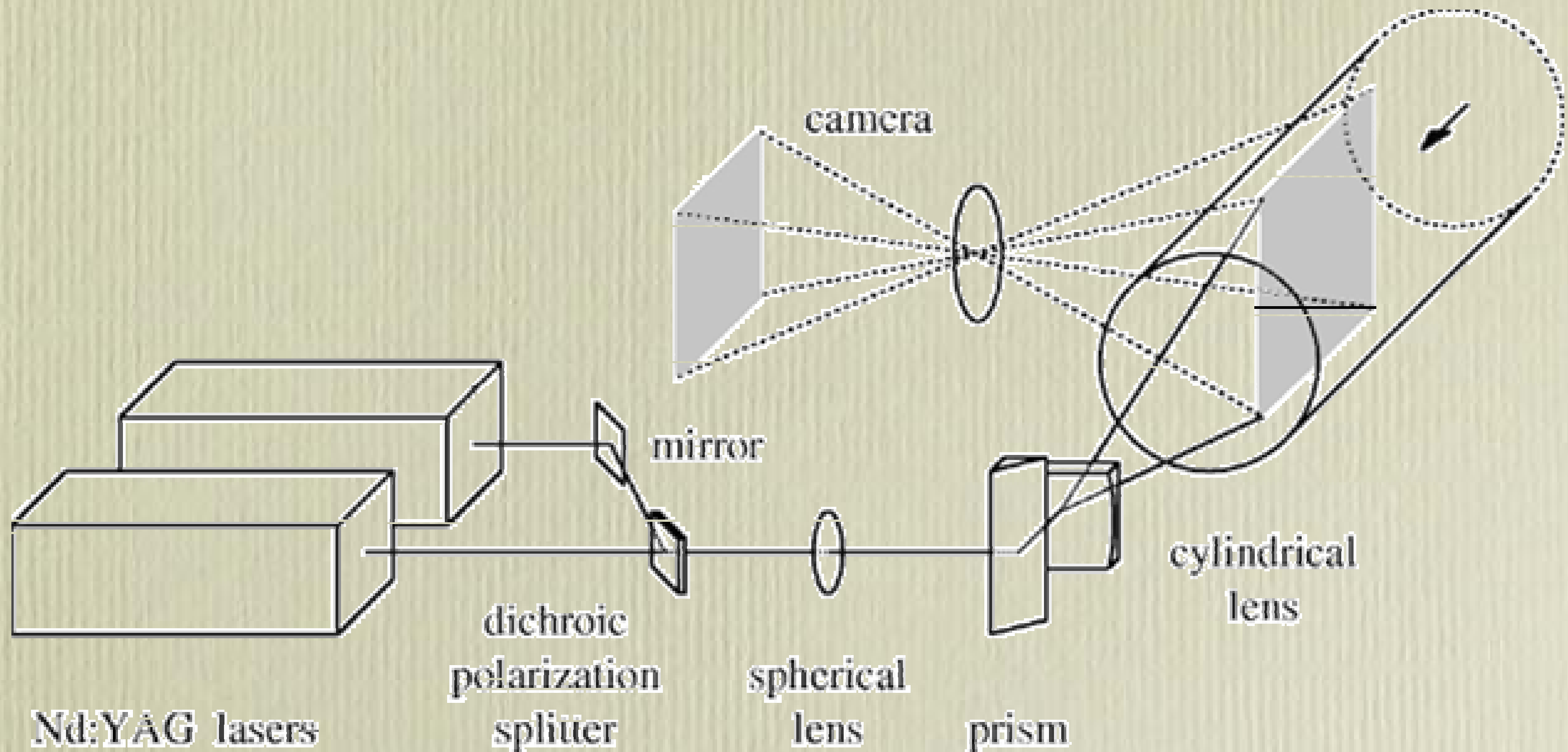


Figure courtesy of DANTEC Measurement Technology

Visualization vs. Measurement?

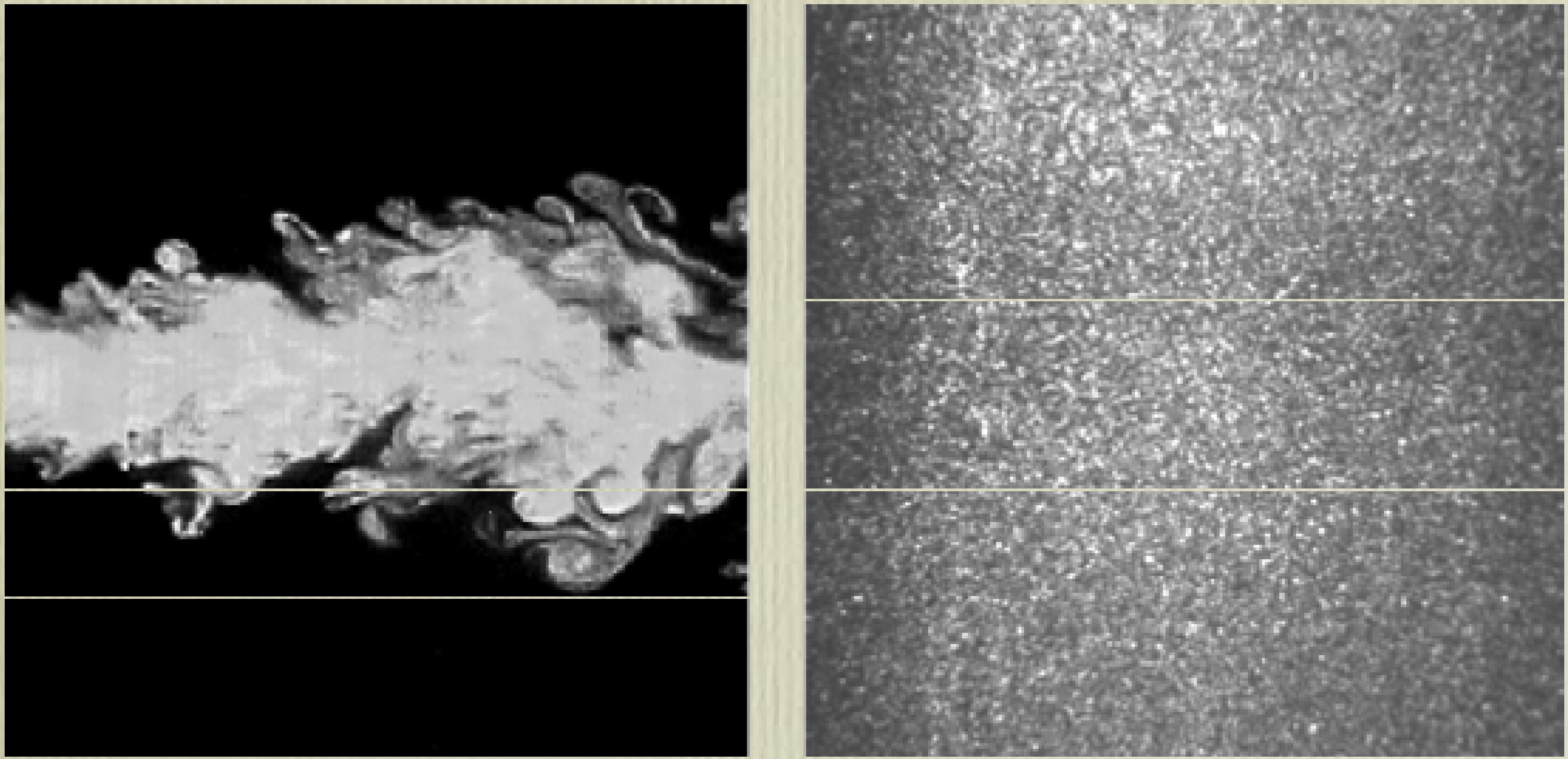
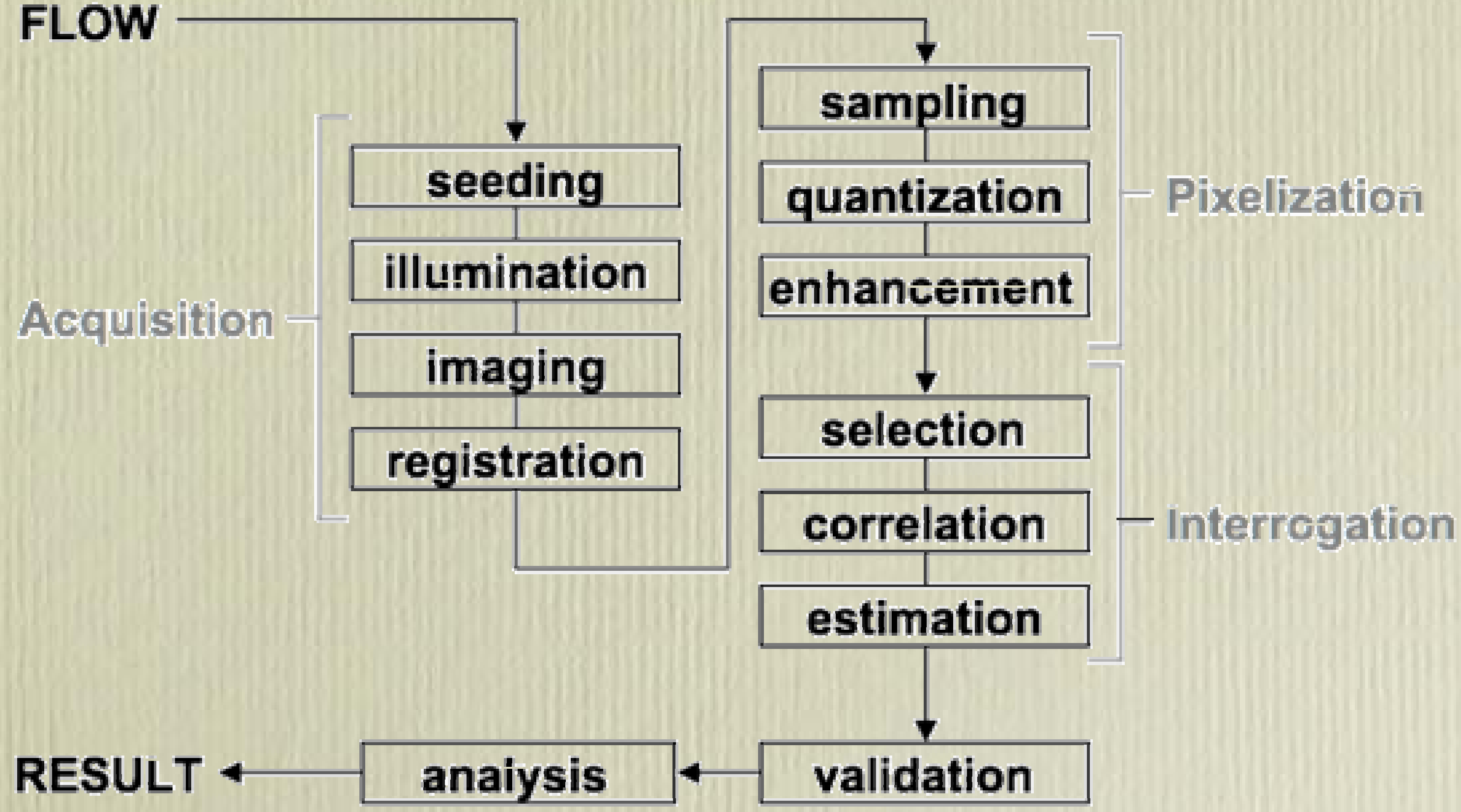
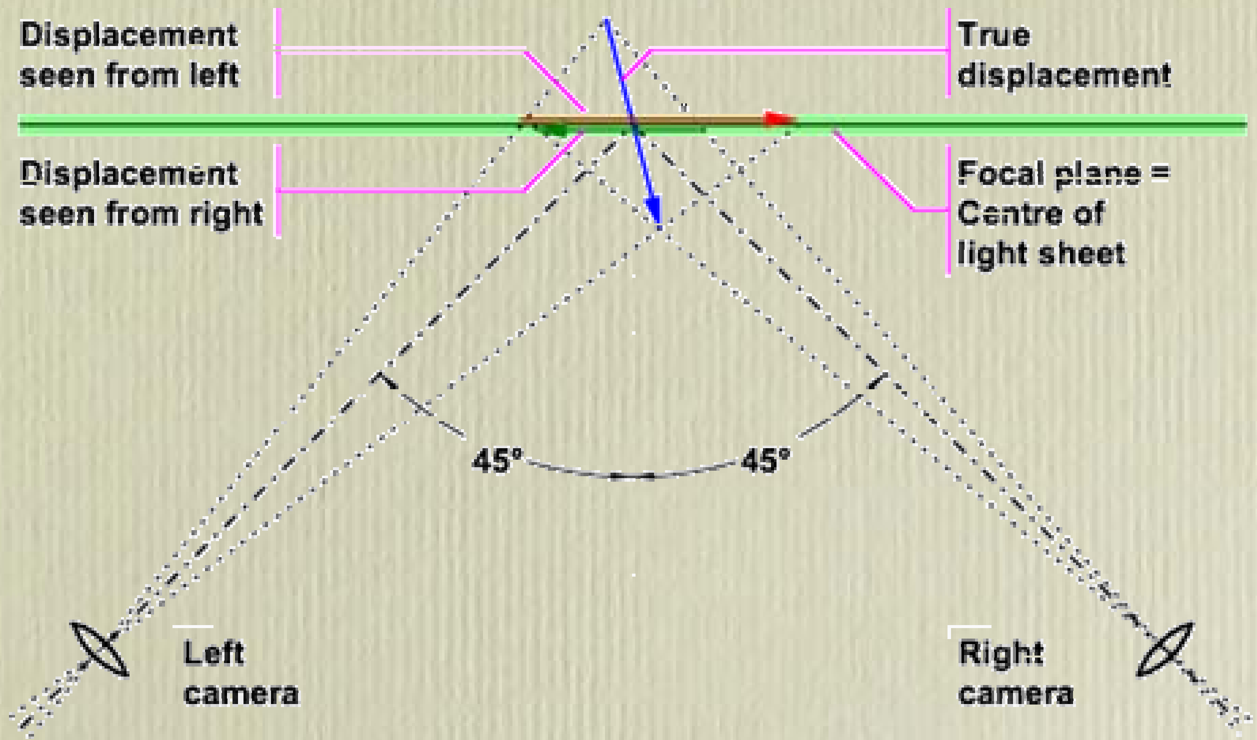


Figure courtesy of DANTEC Measurement Technology

PIV: Data Flow



Stereo PIV: Error Reduction



Make measurements of flow through the measurement plane.

Figure courtesy of DANTEC Measurement Technology