# 7. Principles of
# Phase Doppler Anemometry

**Dantec Measurement Technology**

**http://www.dantecmt.com**

# General features of PDA

- Extension of the LDA principle
- Simultaneous measurement of velocity (up to 3 components) and size of spherical particles as well as mass flux, concentration etc.
- First publication by Durst and Zaré in 1975
- First commercial instrument in 1984
- Non-intrusive measurement (optical technique), on-line and in-situ
- Absolute measurement technique (no calibration required)
- Very high accuracy
- Very high spatial resolution (small measurement volume)

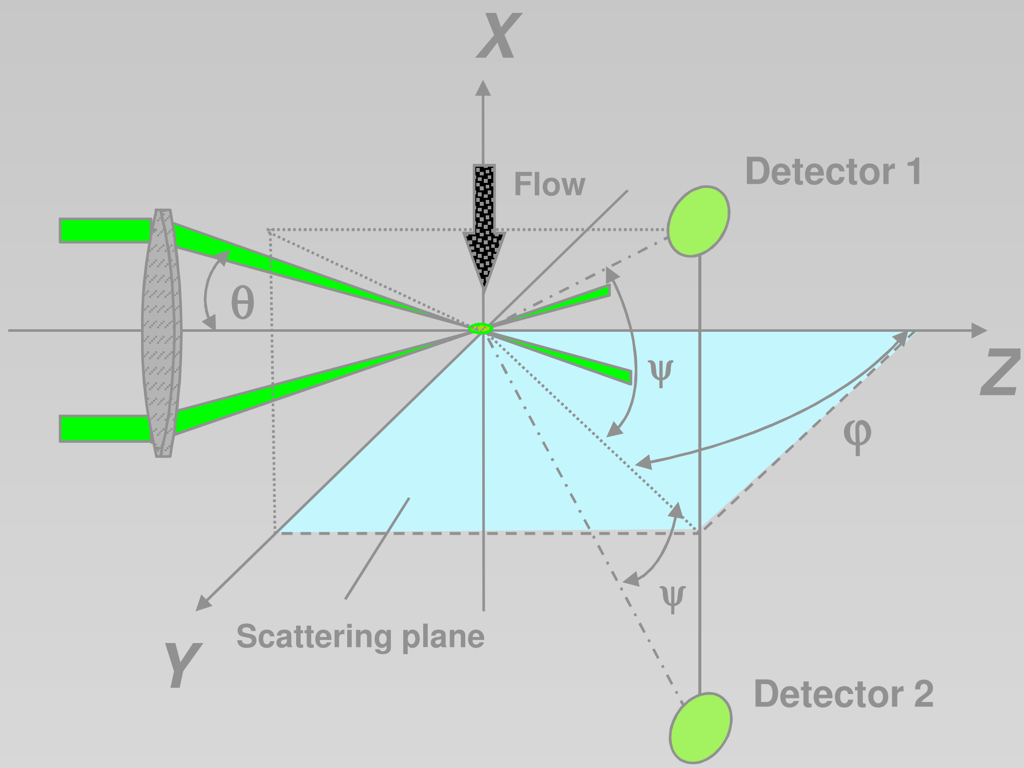
# Preconditions for the application of PDA

- **Optical access to the measurement area (usually from two directions)**
- **Sphericity of particles (droplets, bubbles, solids)**
- **Homogeneity of particle medium**
  **(slight inhomogeneities may be tolerated if the concentration of the inhomogeneities is low and if the size of the inhomogeneities is much smaller than the wavelength used)**
- **Refractive indices of the particle and the continuous medium must usually be known**
- **Particle size between ca. 0.5 µm and several millimeters**
- **Max. particle number concentration is limited**

# Principle setup of PDA

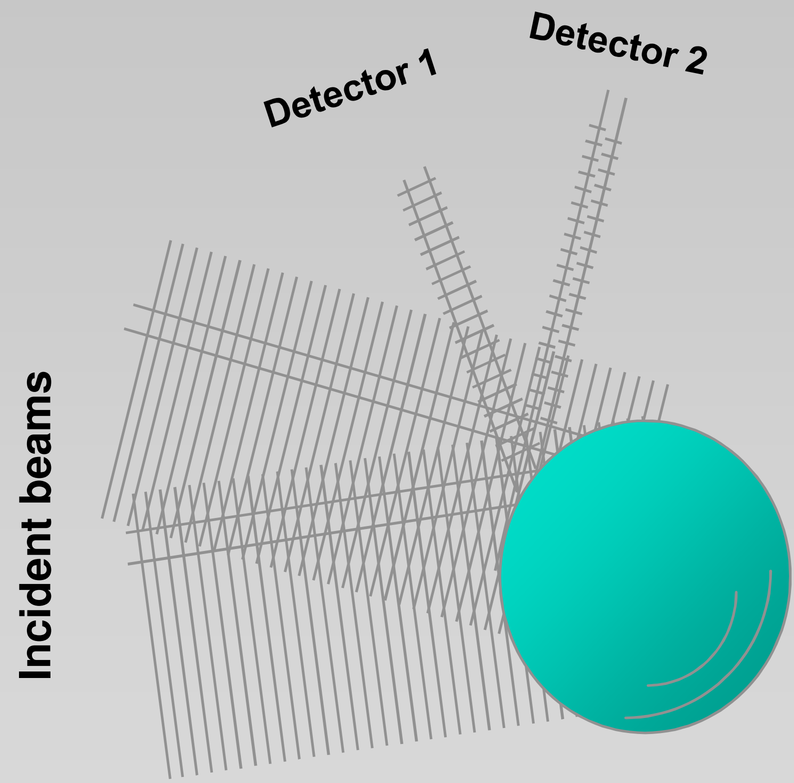
## Optical parameters of a PDA setup:

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



# Optical principle of PDA

- **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**



# Phase relationships

**The phase shift between two detectors is:**

**For reflection:**

$$\Phi = \frac{2\pi d_p}{\lambda} \frac{\sin\theta \ \sin\psi}{\sqrt{2(1-\cos\theta \ \cos\psi \ \cos\phi)}}$$

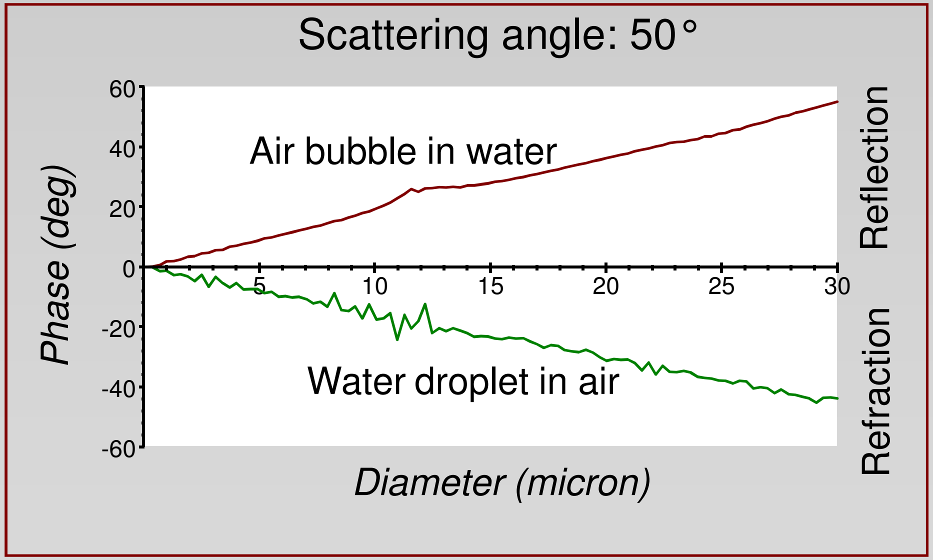
**For 1st order refraction:**

$$\Phi = \frac{-2\pi d_p}{\lambda} \frac{n_{rel} \ \sin\theta \ \sin\psi}{\sqrt{2(1+\cos\theta \ \cos\psi \ \cos\phi)(1+n_{rel}^2 - n_{rel}\sqrt{2(1+\cos\theta \ \cos\psi \ \cos\phi}}}$$

**No calibration constant is contained in these equations.**

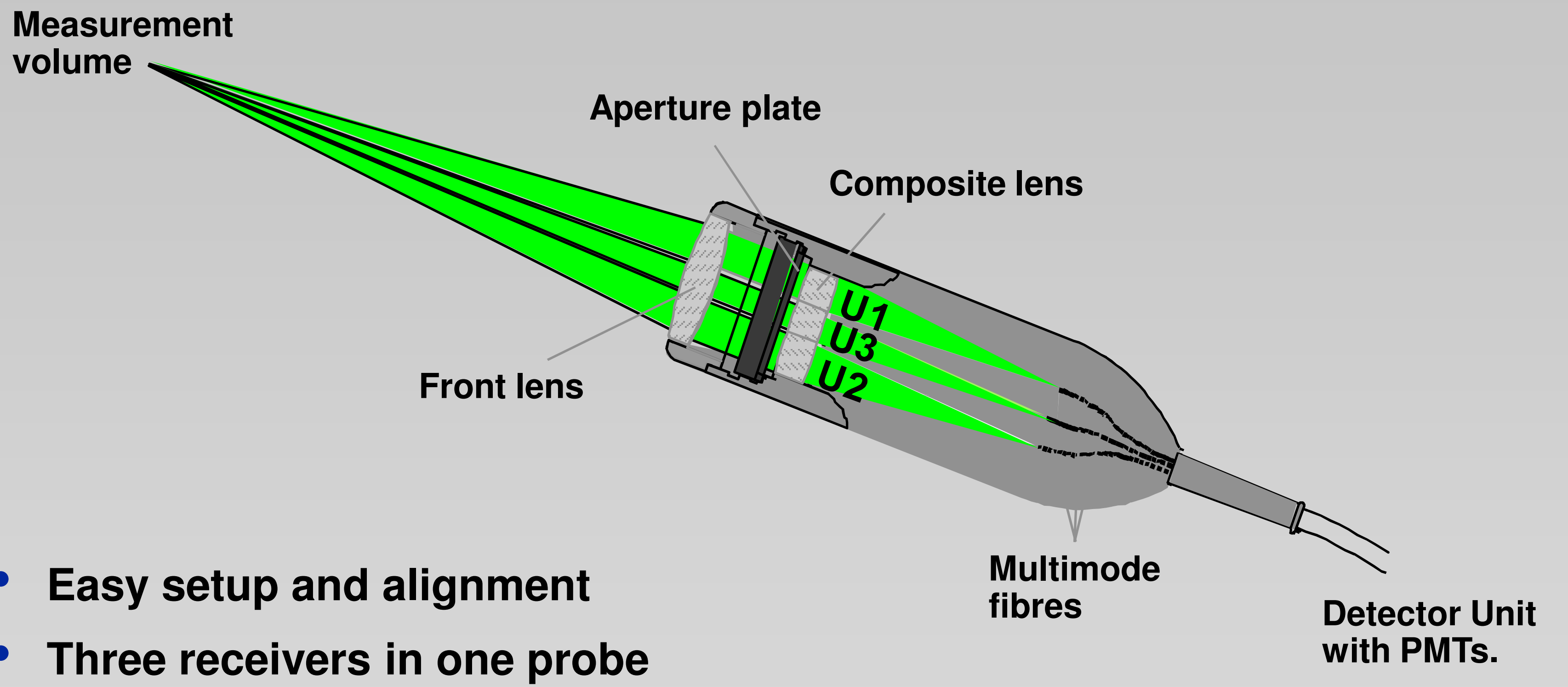
# Phase - diameter linearity

- **A linear relationship between measured phase difference and particle diameter only exists, if the detector is positioned such that one light scattering mode dominates.**
- **Simultaneous detection of different scattering modes of comparable intensity leads to non-linearities in the phase-diameter relationship.**




DANTEC Measurement Technology

# Dantec 57X40 FiberPDA




- Easy setup and alignment
- Three receivers in one probe
- Exchangeable aperture masks
- Up to three velocity components

# Applications

- Sprays and liquid atomization processes
  - Water sprays
  - Fuel-, diesel injection
  - Paint coating
  - Agricultural sprays
  - Medical, pharmaceutical sprays
  - Cosmetic sprays
- Powder production
  - Spray drying
  - Liquid metal atomization
- Bubble dynamics
  - Cavitation
  - Aeration
  - Multiphase mass transfer

# Automotive Fuel Injection

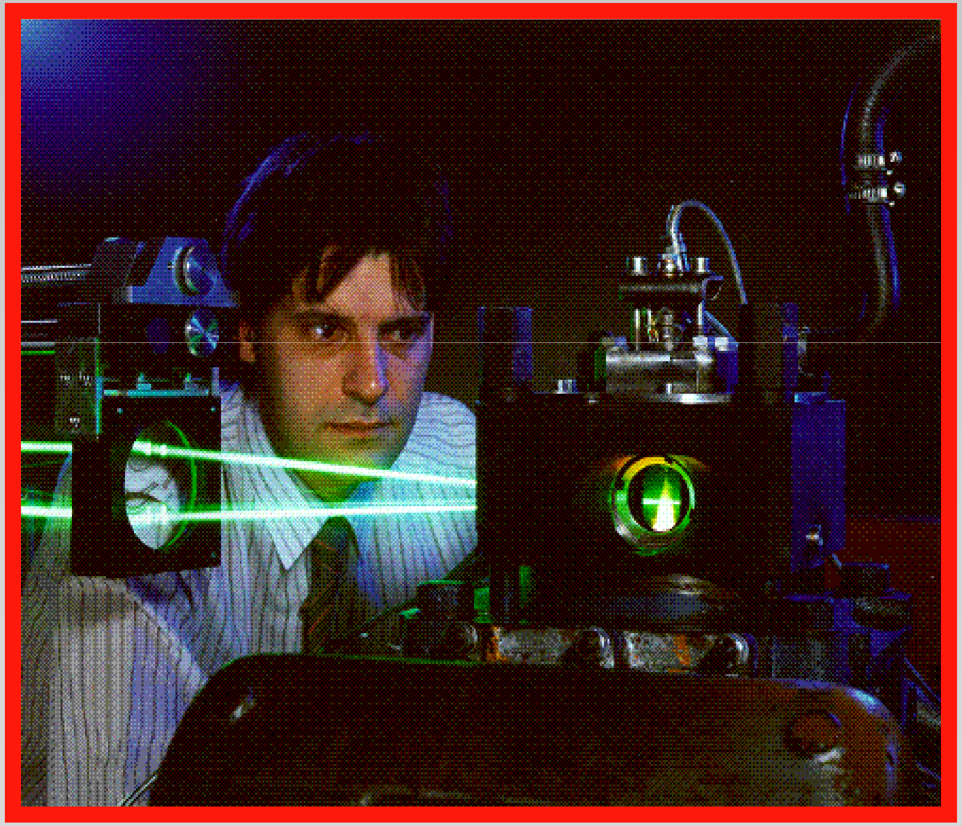


Photo: AVL, Graz, Austria

# Nozzle Design

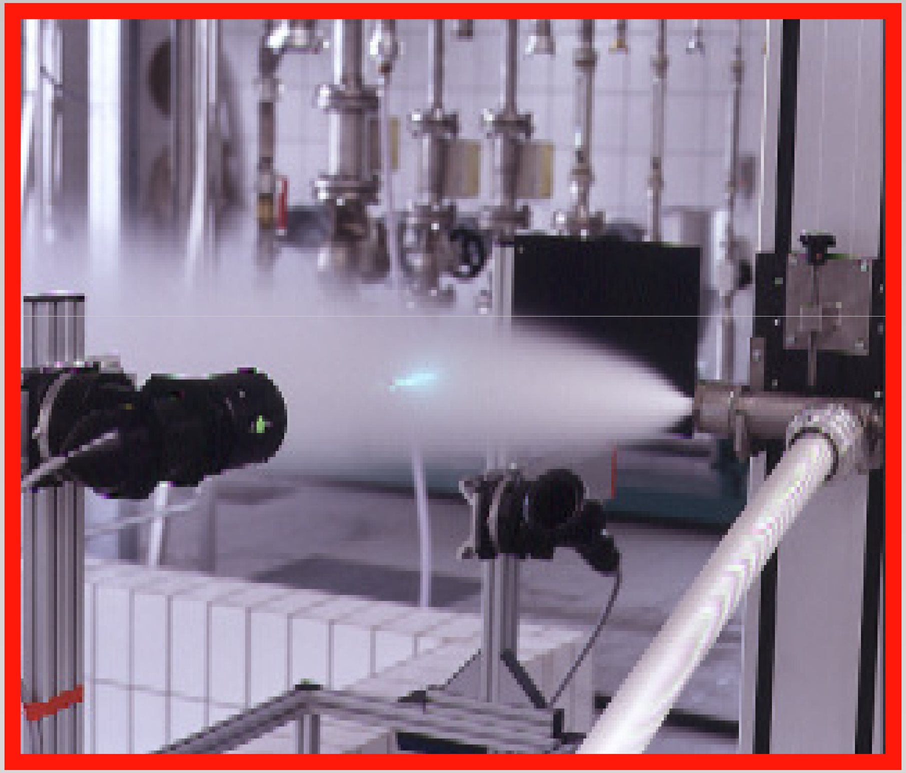


Photo: Gustav Schlick GmbH & Co., Untersiemau, Germany

# Aircraft Engine Fuel Injection

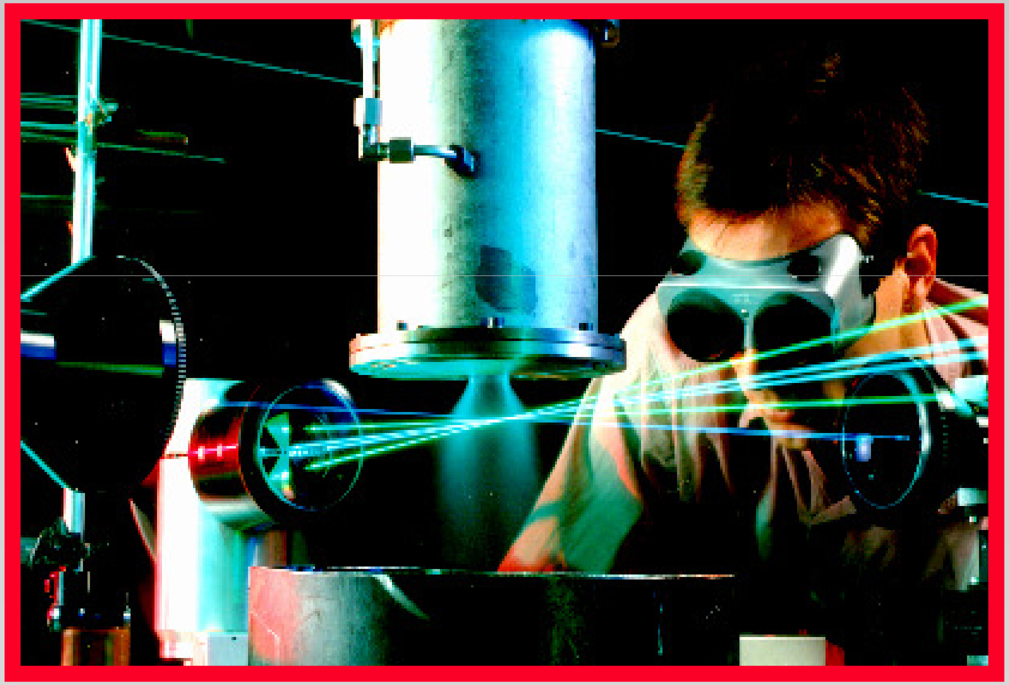
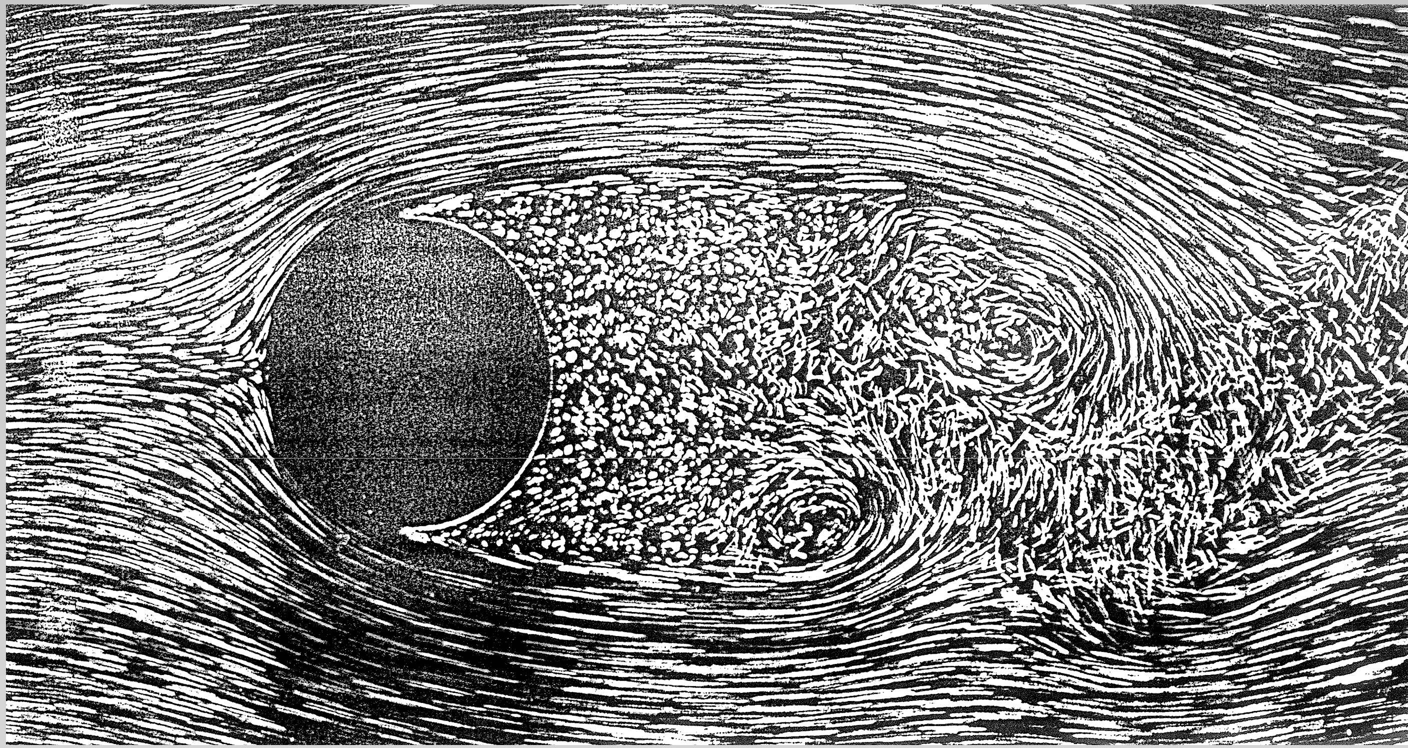
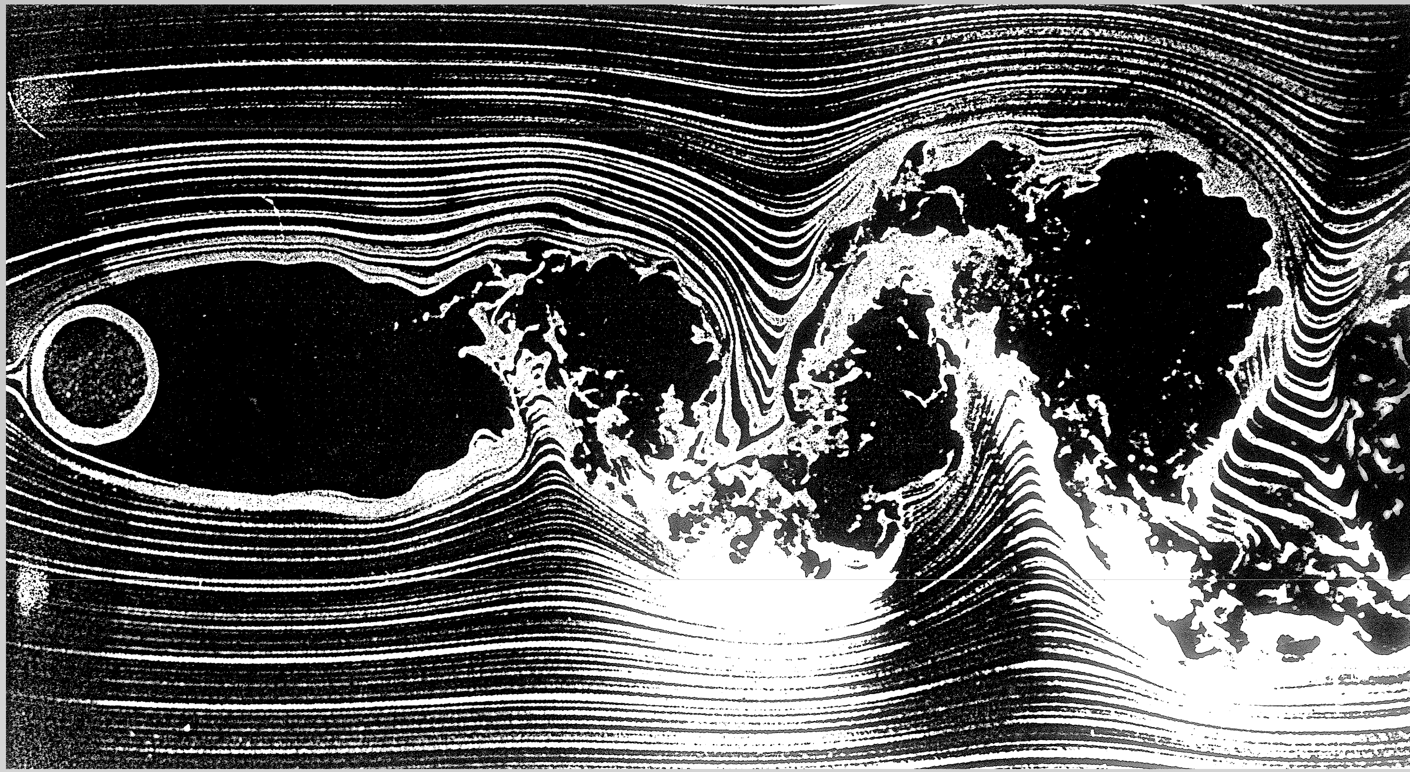


Photo: DLR, Institut für Antriebstechnik, Köln, Germany

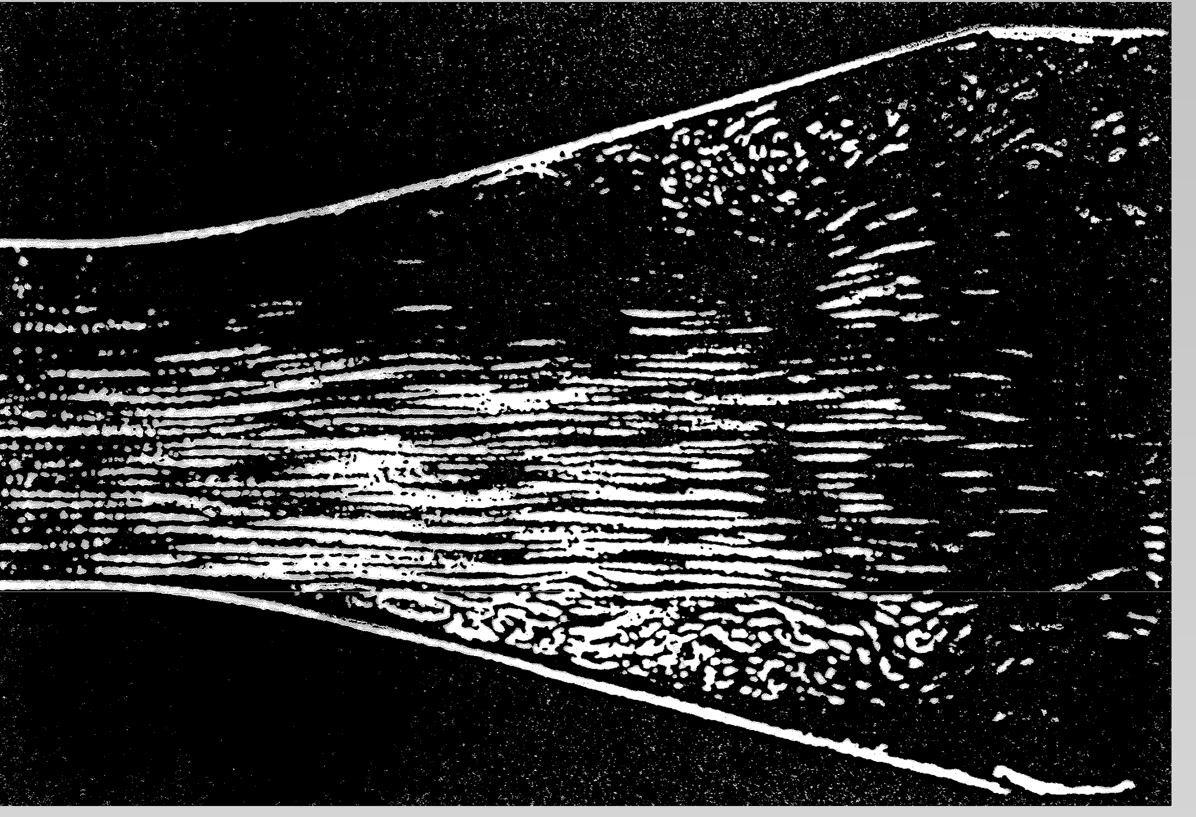
# 9. Light sheet flow visualisation



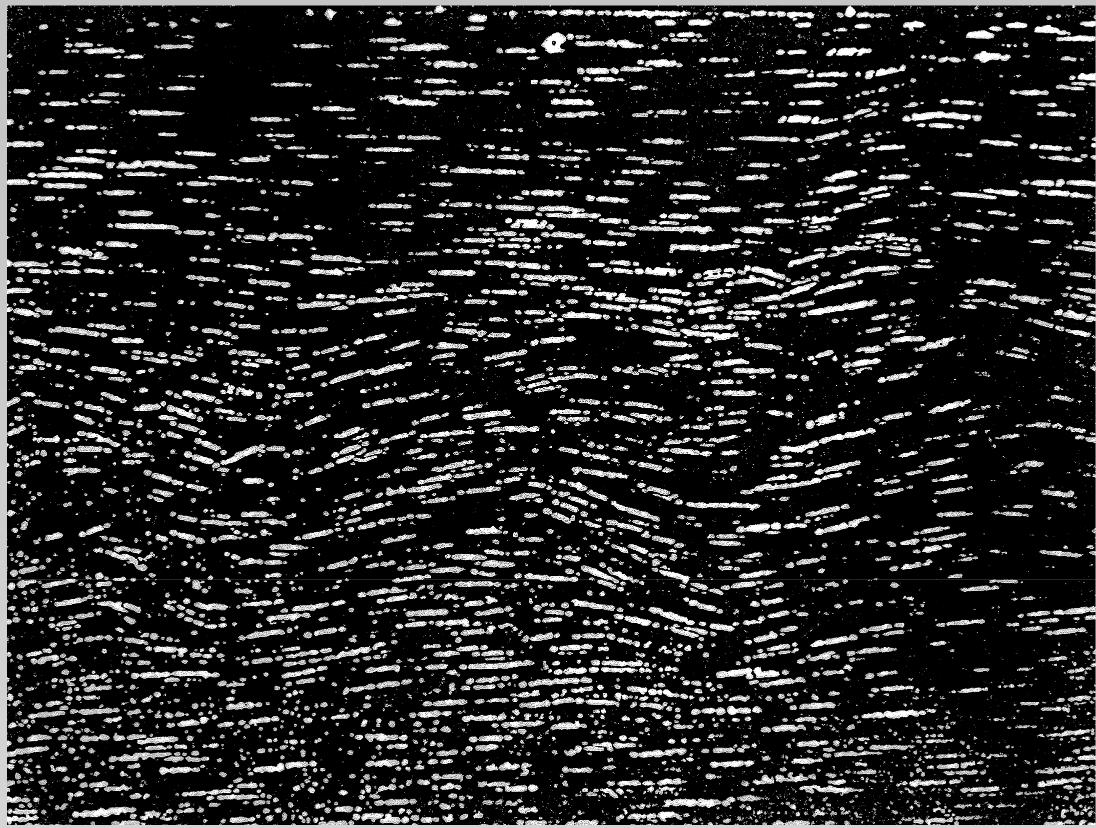
Flow visualised in the vicinity of a cylinder. Re = 2 000. Air bubbles in water. (Van Dyke: An Album of Fluid Motion, Parabolic Press, stanford, California, 1982)



Flow visualised in the vicinity of a cylinder. Re = 10 000.
Hydrogene bubbles in water. (Van Dyke: An Album of Fluid Motion, Parabolic Press, Stanford, California, 1982)

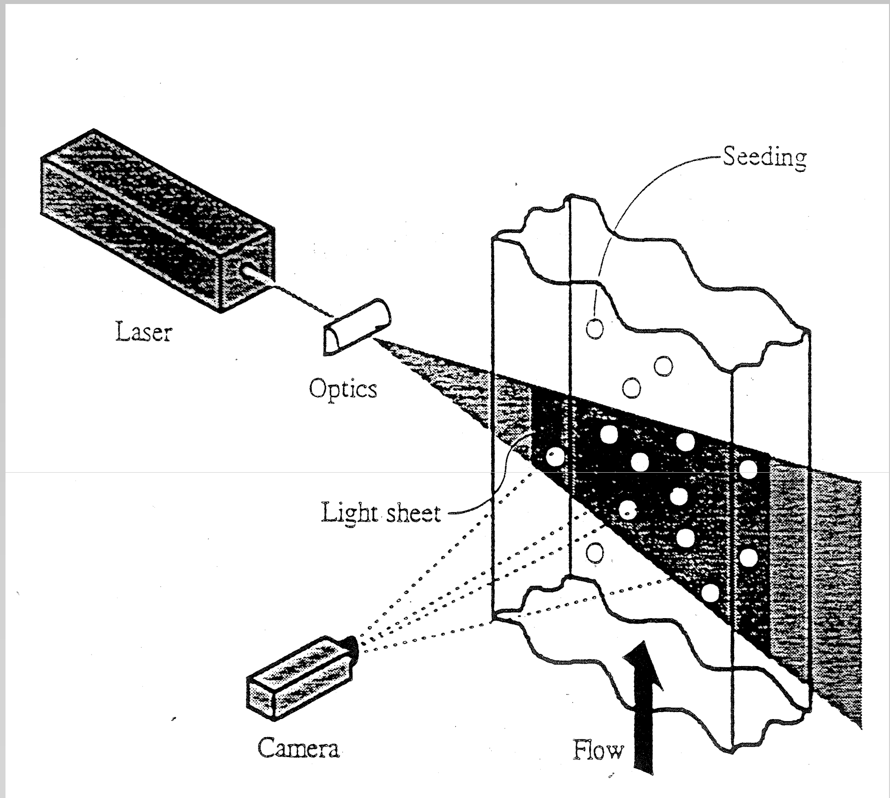


Flow visualised in a diffuser. Air bubbles in water. (Kaufmann, W.: Technische Hydro- und Aeromechanik, Springer Verlag, 1963)

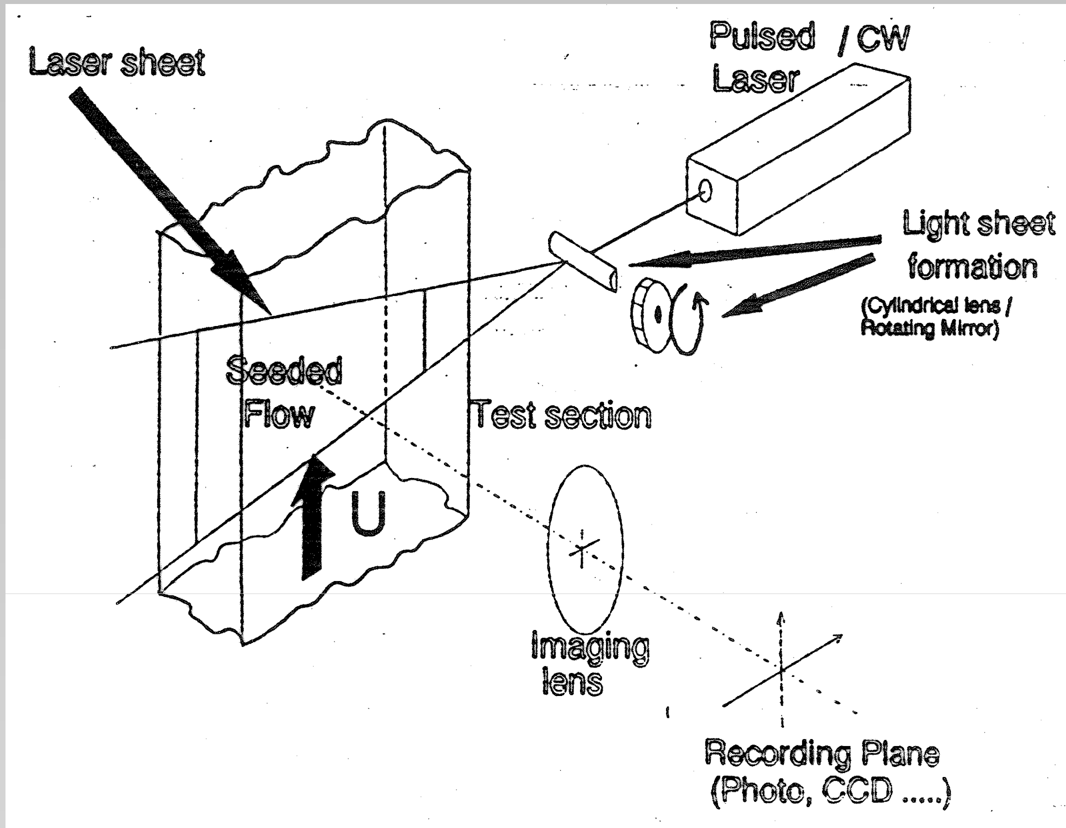


Particle Tracking Velocimetry. Flow downstream of a cylinder. (Agui, J. C. A., Jimenez, J.: On the Performance of Particle Tracking. J Fluid Mechanics, pp. 447 – 468, 1987)

# 10. Particle Image Velocimetry (PIV)

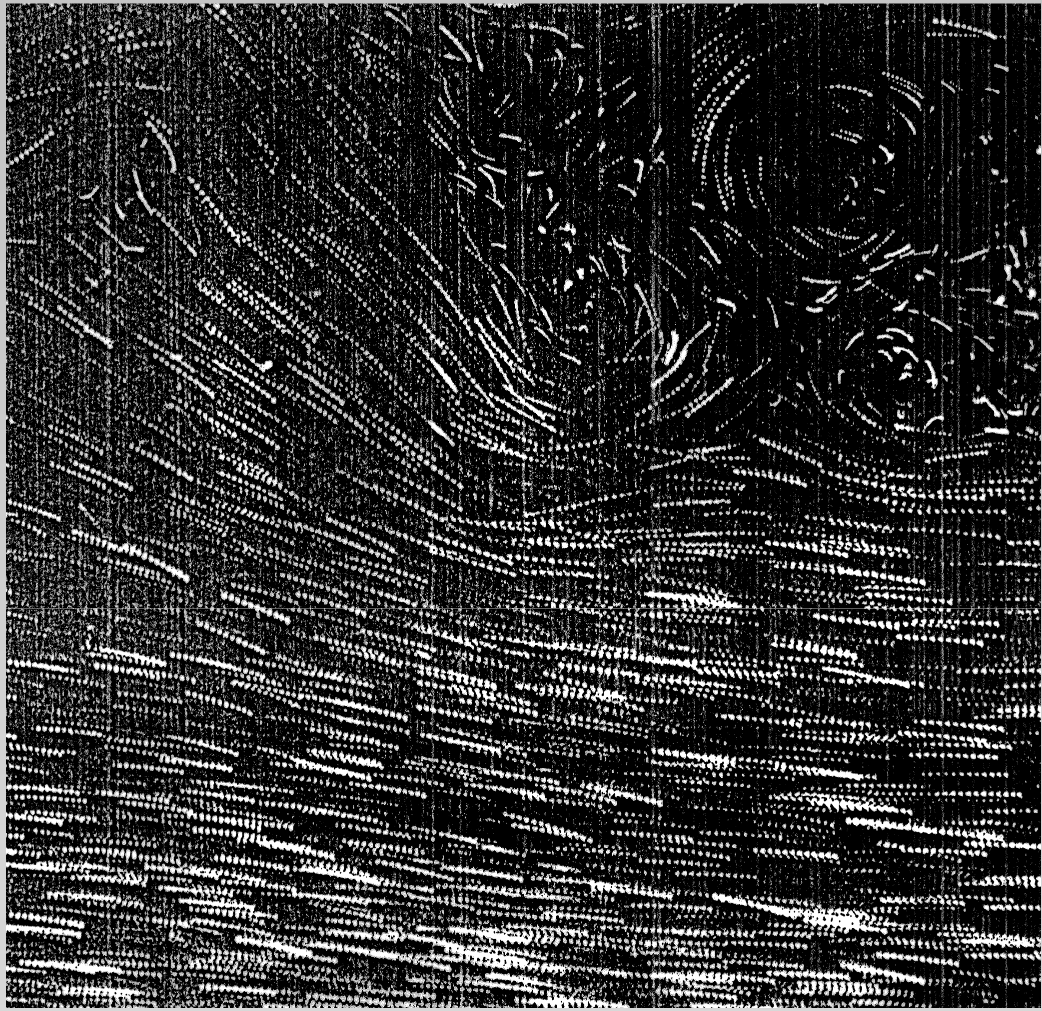



Principle of PIV (Lecture note by Pap, E., Otto-Von-Guericke Universitaet Magdeburg, Institut für Strömungstechnik und Thermodynamik, Lehrstuhl für Strömungsmaschinen)

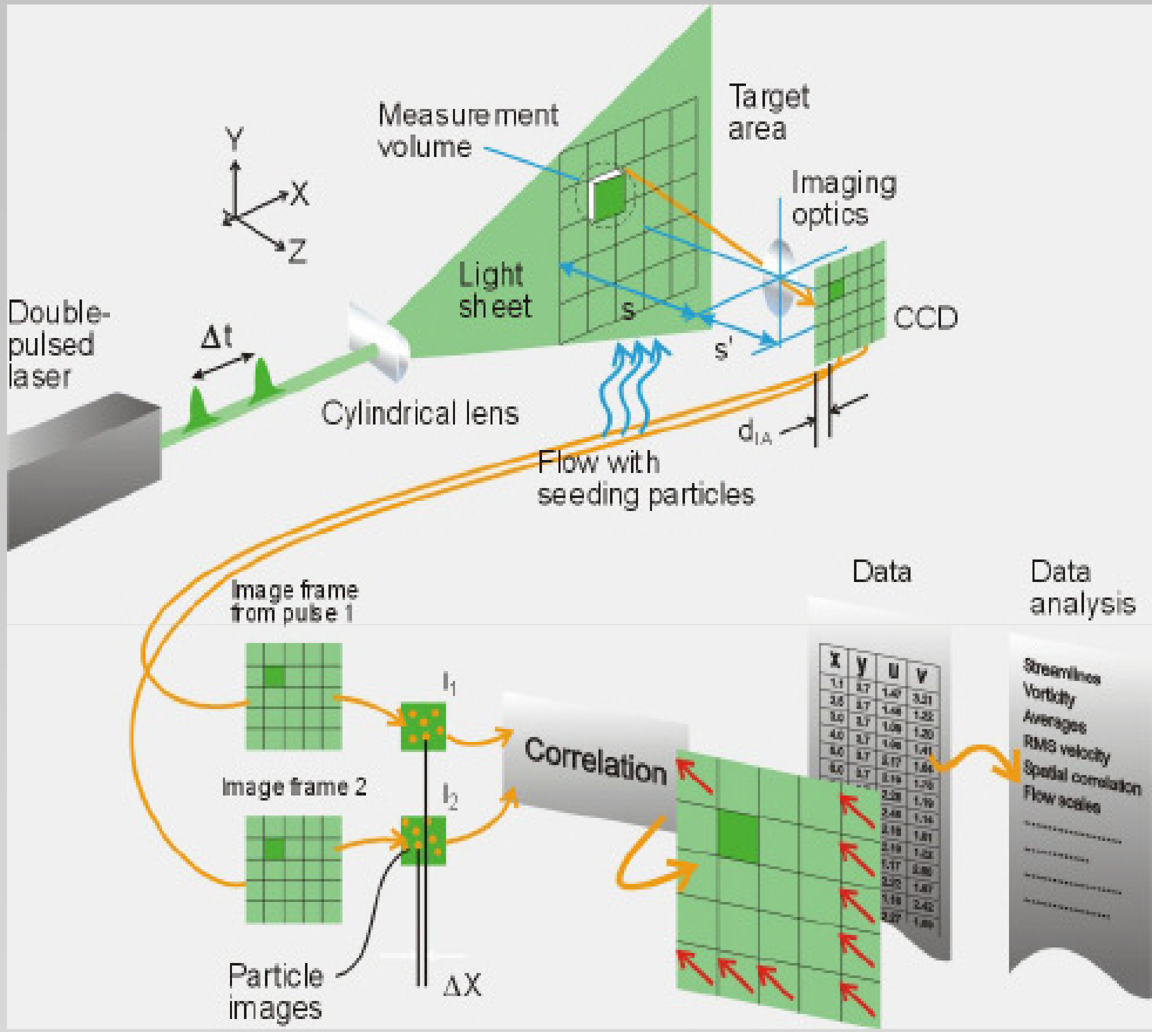



PIV arrangement with rotating mirror laser sheet generator (Lecture note by Pap, E., Otto-Von-Guericke Universitaet Magdeburg, Institut für Strömungstechnik und Thermodynamik, Lehrstuhl für Strömungsmaschinen)

DANTEC
Measurement Technology



Typical image originated from multipulse illumination




Summary of PIV http://www.dantecdynamics.com/piv/princip/index.html

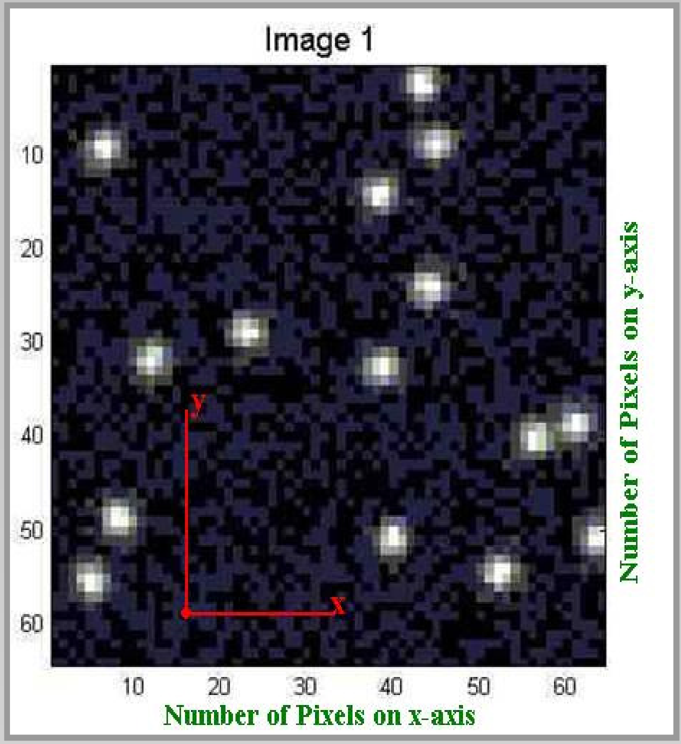



**Image 1 at time t1**

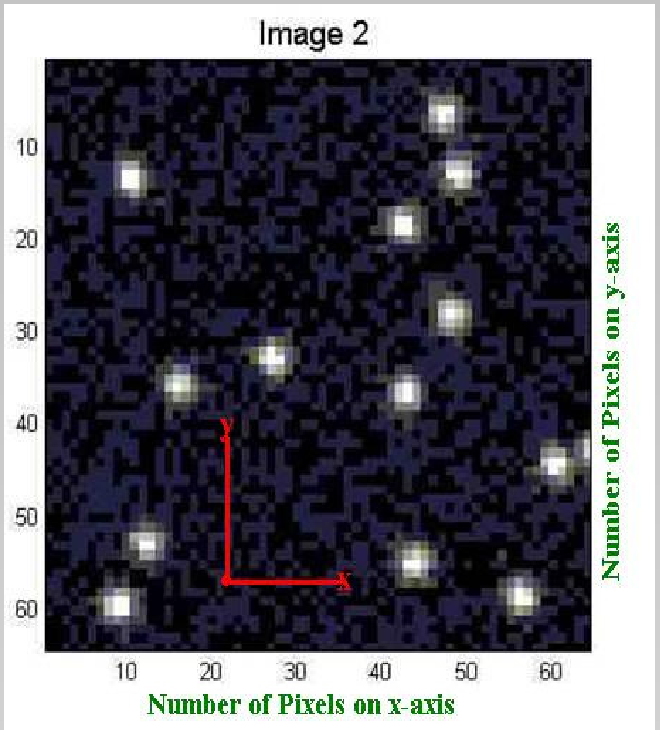
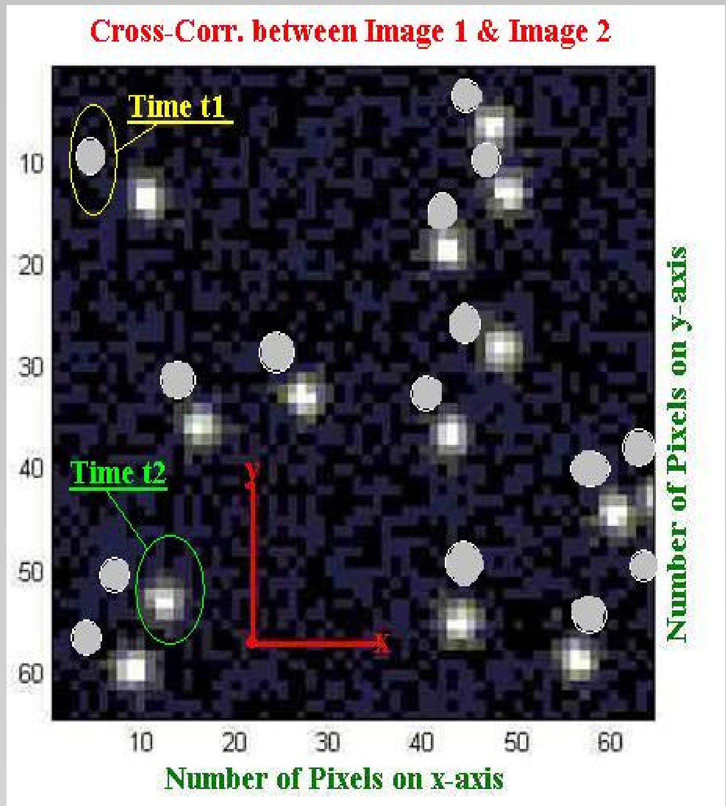



**Image 2 at time t2**

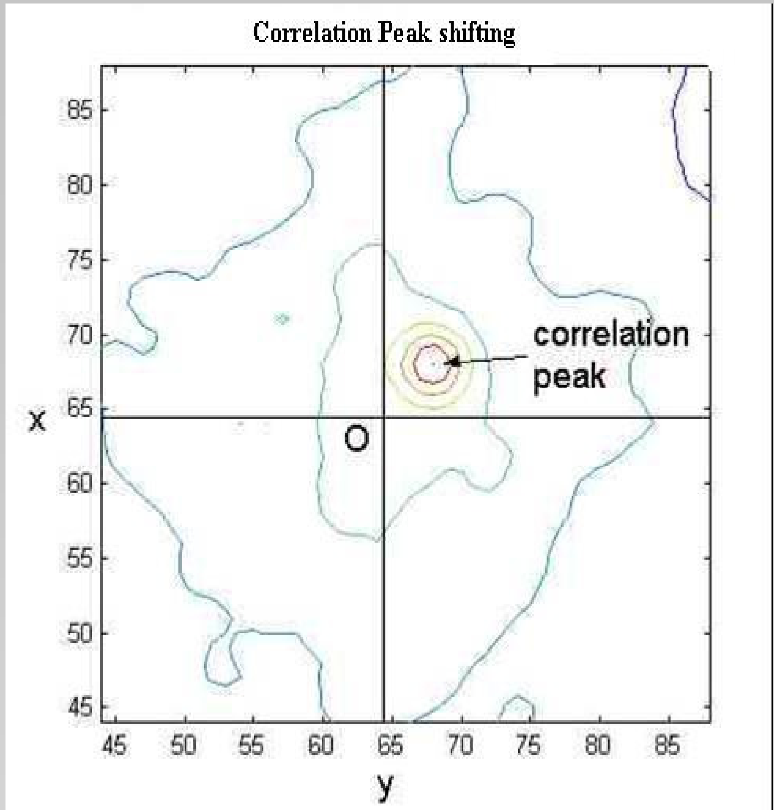
$$\bar{V} = \frac{\Delta \bar{x}}{\Delta t} \qquad \Delta \bar{x} = ?$$

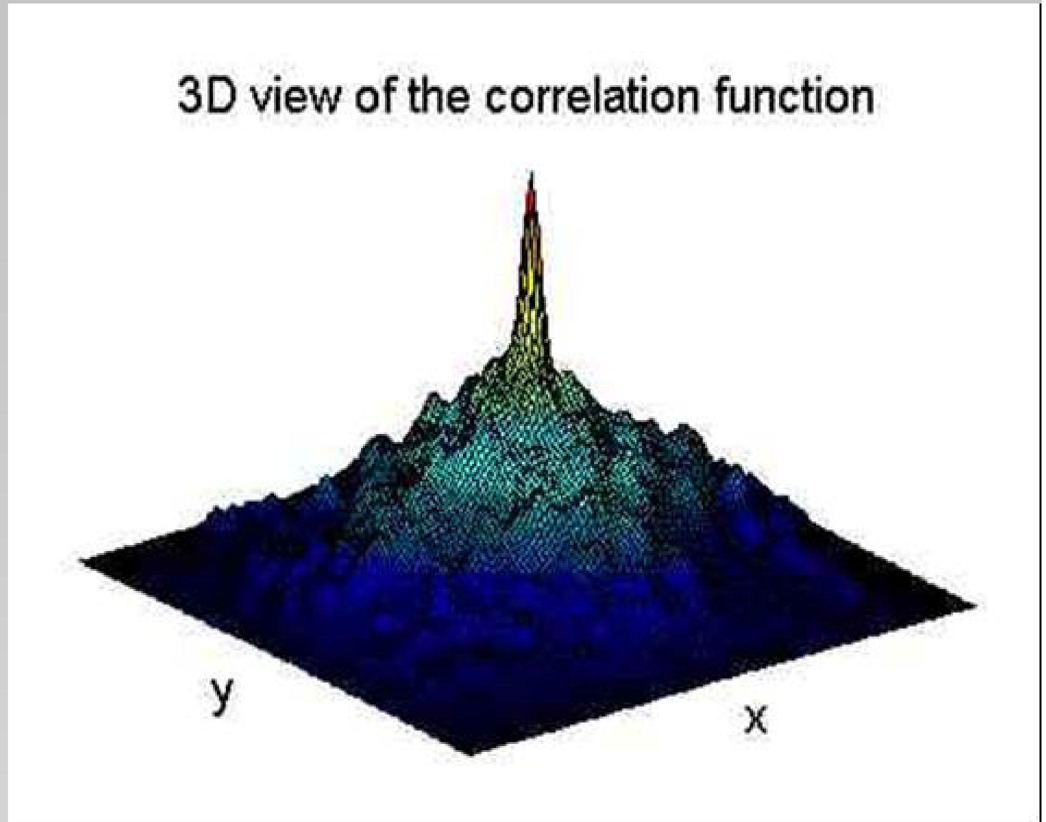
PIV Lecture_Notes, "Particle Image Velocimetry", University of WARWICK, Optical Engineering Laboratory (OEL)

DANTEC Measurement Technology



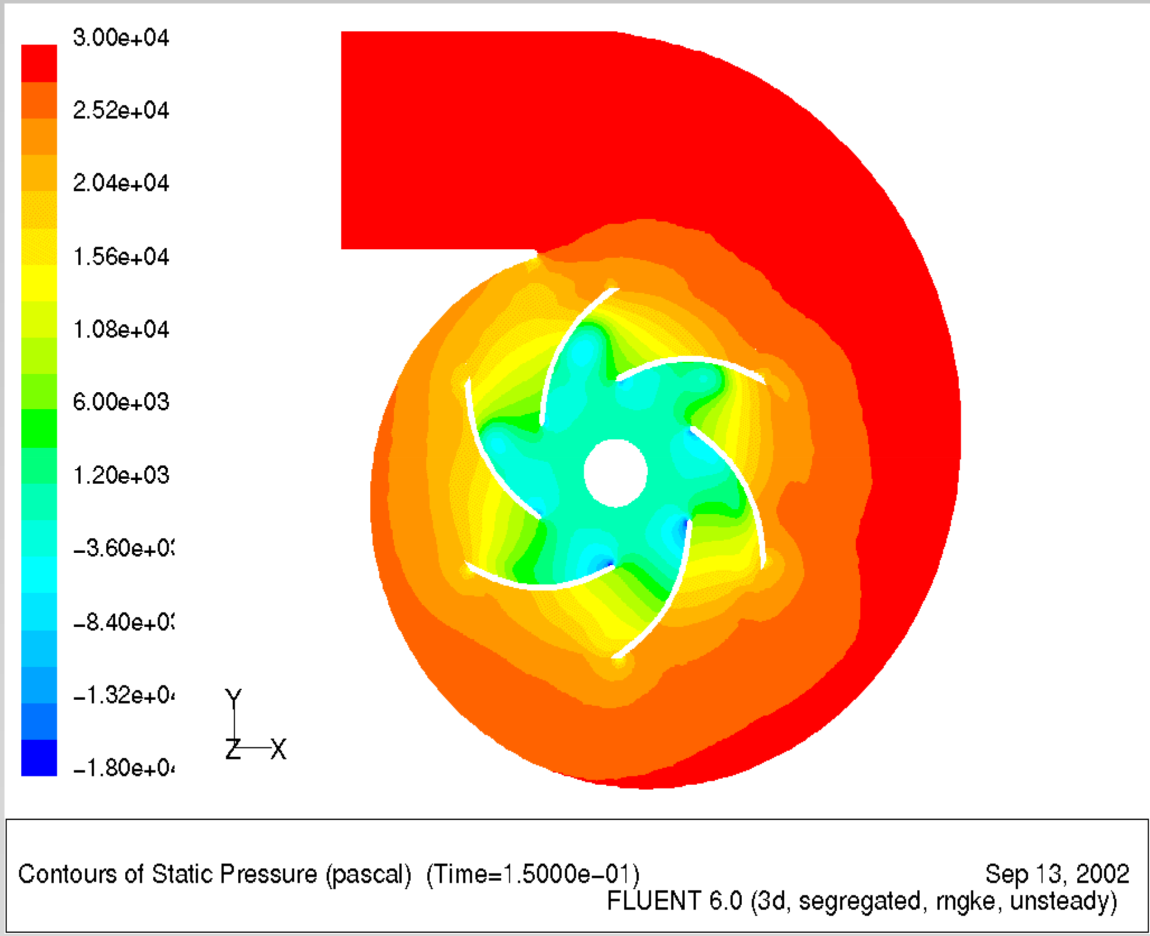

**Maximum cross-correlation between Image 1 & Image 2**

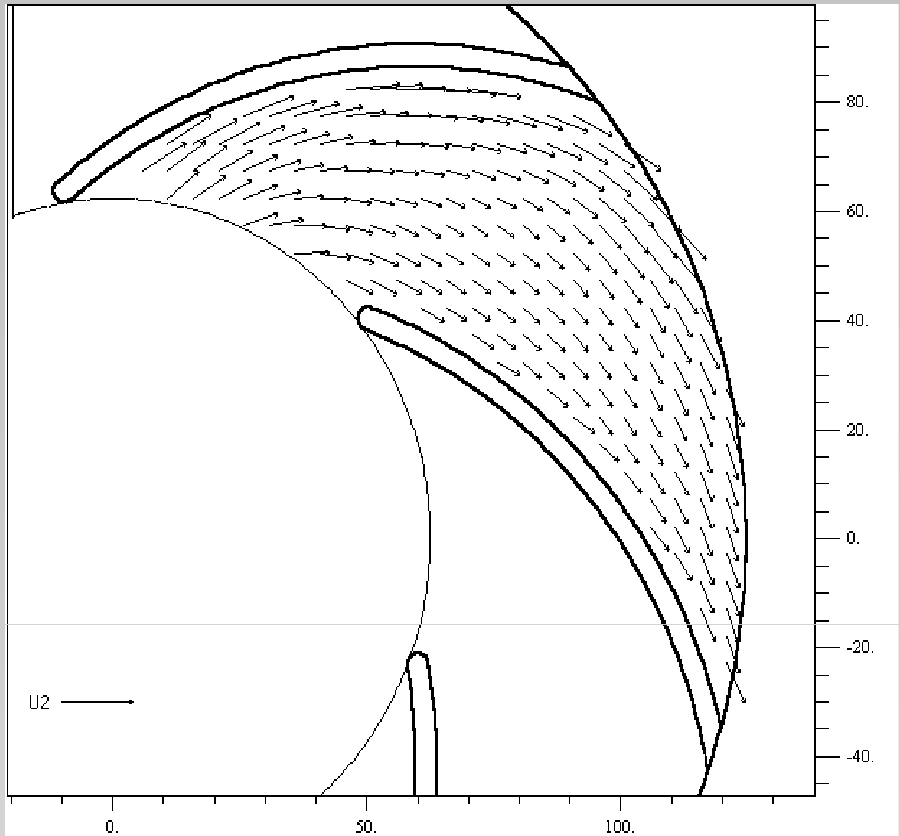


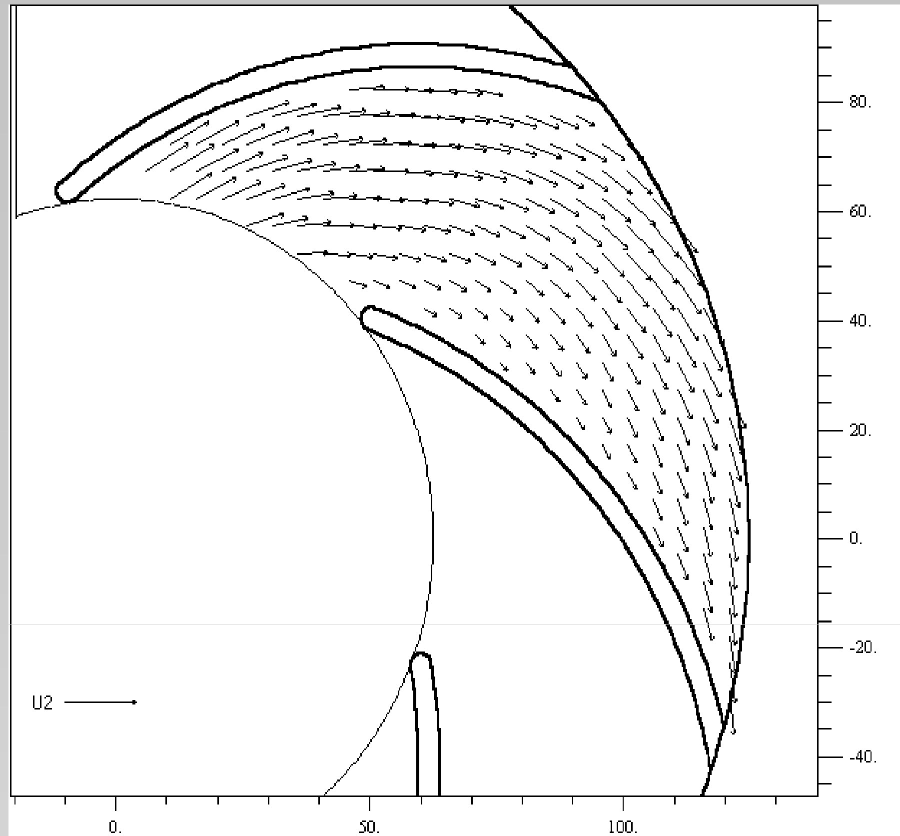




PIV Lecture_Notes, “Particle Image Velocimetry”, University of WARWICK, Optical Engineering Laboratory (OEL)

# Radial pump simulation: comparison of simulated flow field and PIV data





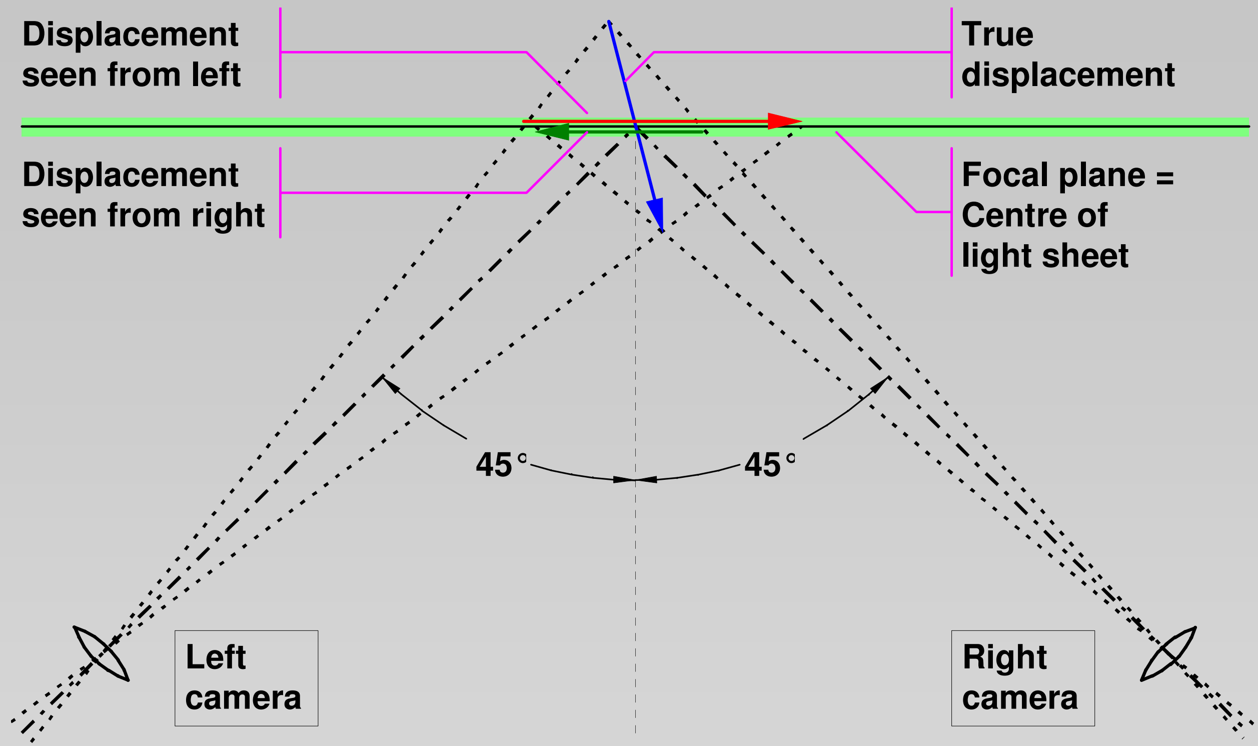

PIV measurement
(Otto-Von-Guericke
Universitaet Magdeburg)

FLUENT simulation
(Dept. of Fluid Mechanics, BME)

# FlowManager 3D-PIV
# (Stereo PIV)

- **Theory of stereoscopic PIV**
- **Dantec 3D-PIV software**
- **Application example:**
  **3D-PIV in an automotive wind tunnel**
  *(used as example through the slide show)*

# Fundamentals of stereo vision




**True 3D displacement (ΔX,ΔY,ΔZ) is estimated from a pair of 2D displacements (Δx,Δy) as seen from left and right camera respectively**

DANTEC
Measurement Technology

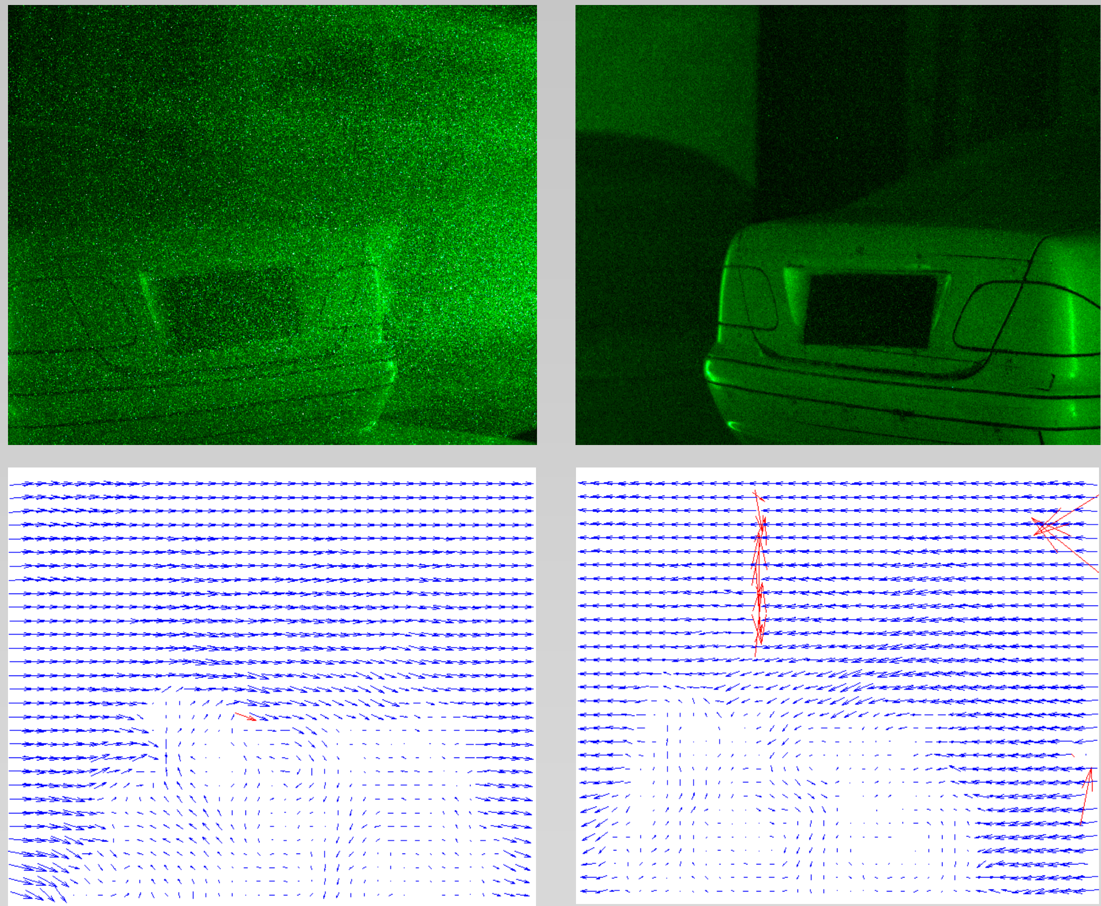
# Left / Right 2D vector maps

Left & Right camera images are recorded simultaneously.

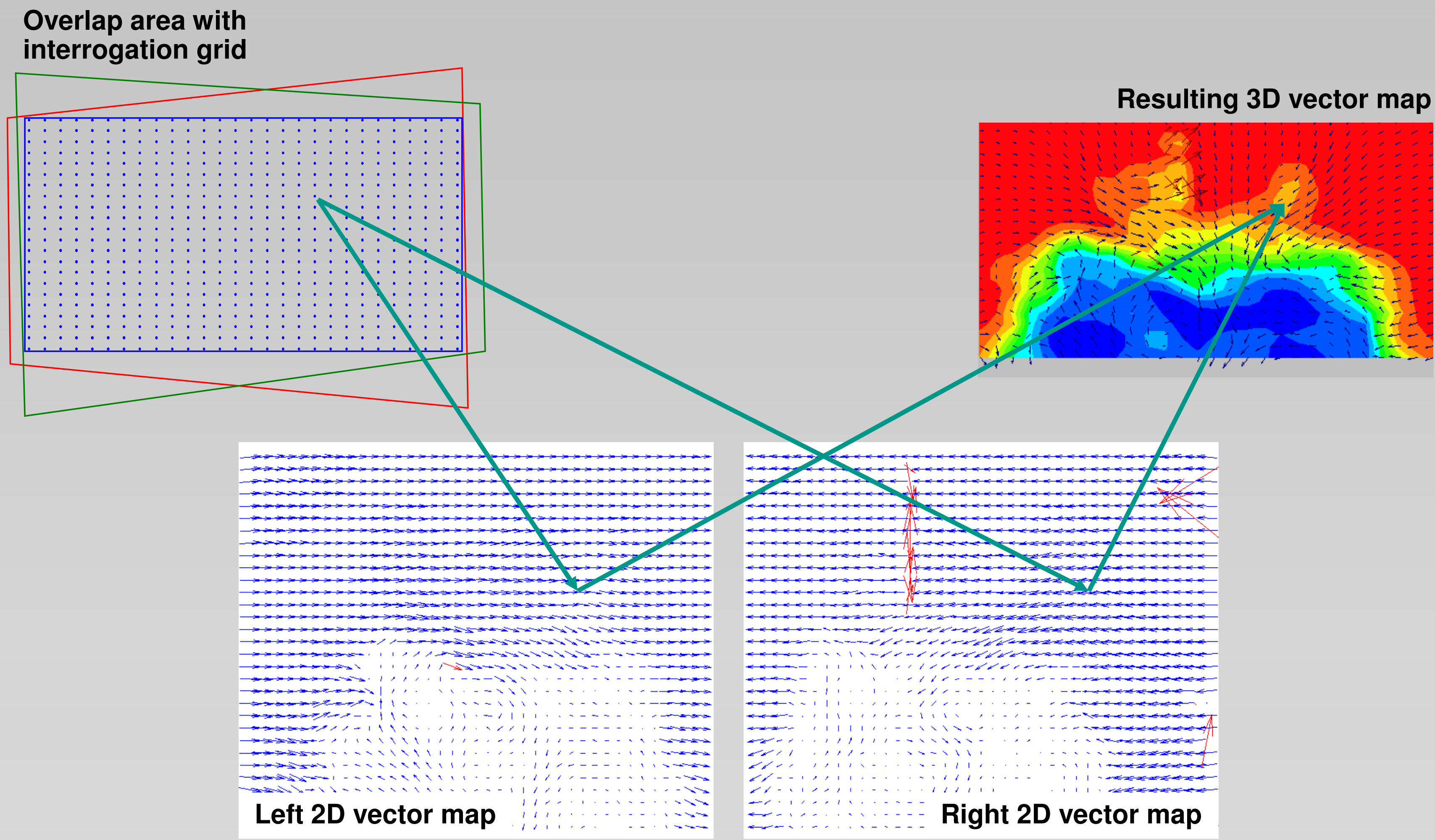
Conventional PIV processing produce 2D vector maps representing the flow field as seen from left & right.

The vector maps are re-sampled in points corresponding to the interrogation grid.

Combining left / right results, 3D velocities are estimated.



# 3D reconstruction




DANTEC
Measurement Technology