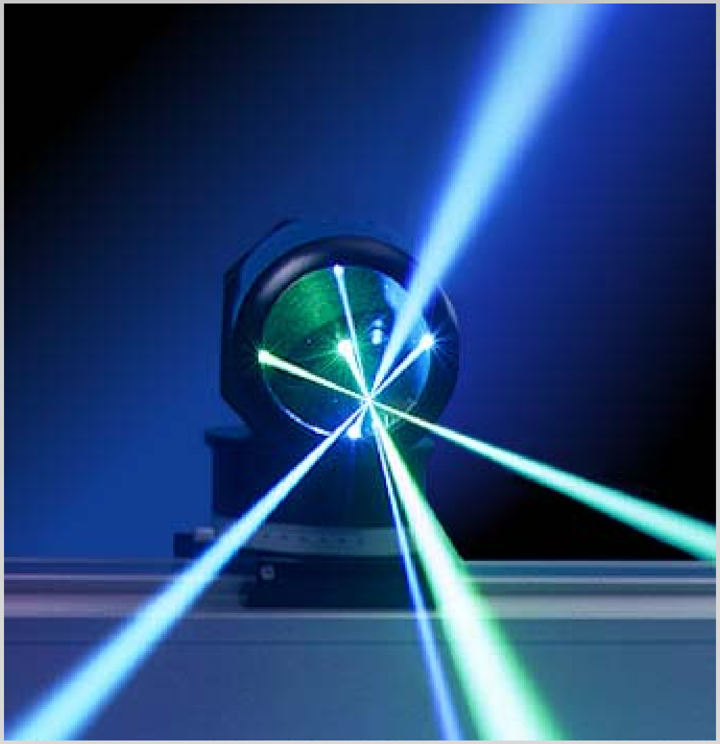
6. Laser Doppler Anemometry

Introduction to principles and applications



DANTEC
Measurement Technology

Characteristics of LDA

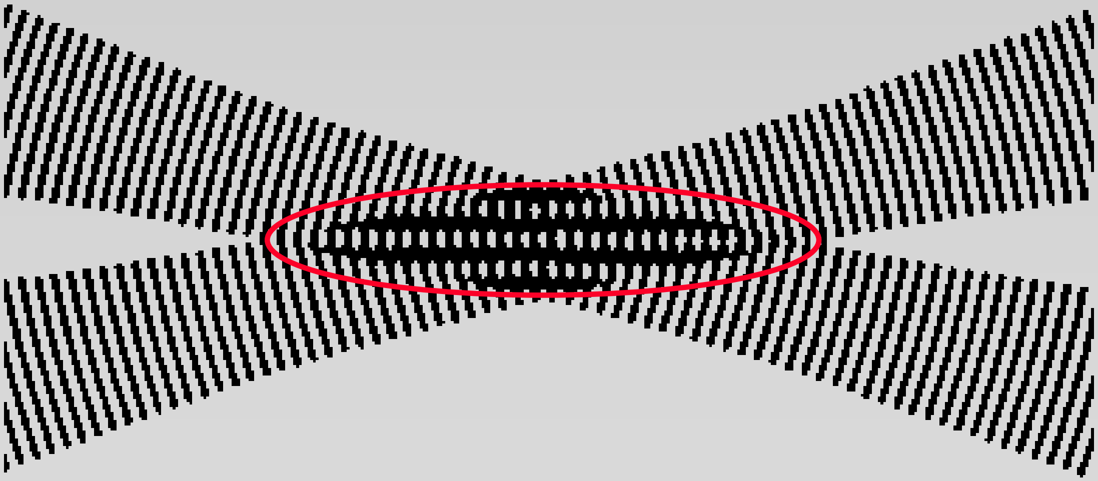
- Invented by Yeh and Cummins in 1964
- Velocity measurements in Fluid Dynamics (gas, liquid)
- Up to 3 velocity components
- Non-intrusive measurements (optical technique)
- Absolute measurement technique (no calibration required)
- Very high accuracy
- Very high spatial resolution due to small measurement volume
- Tracer particles are required

Applications of LDA

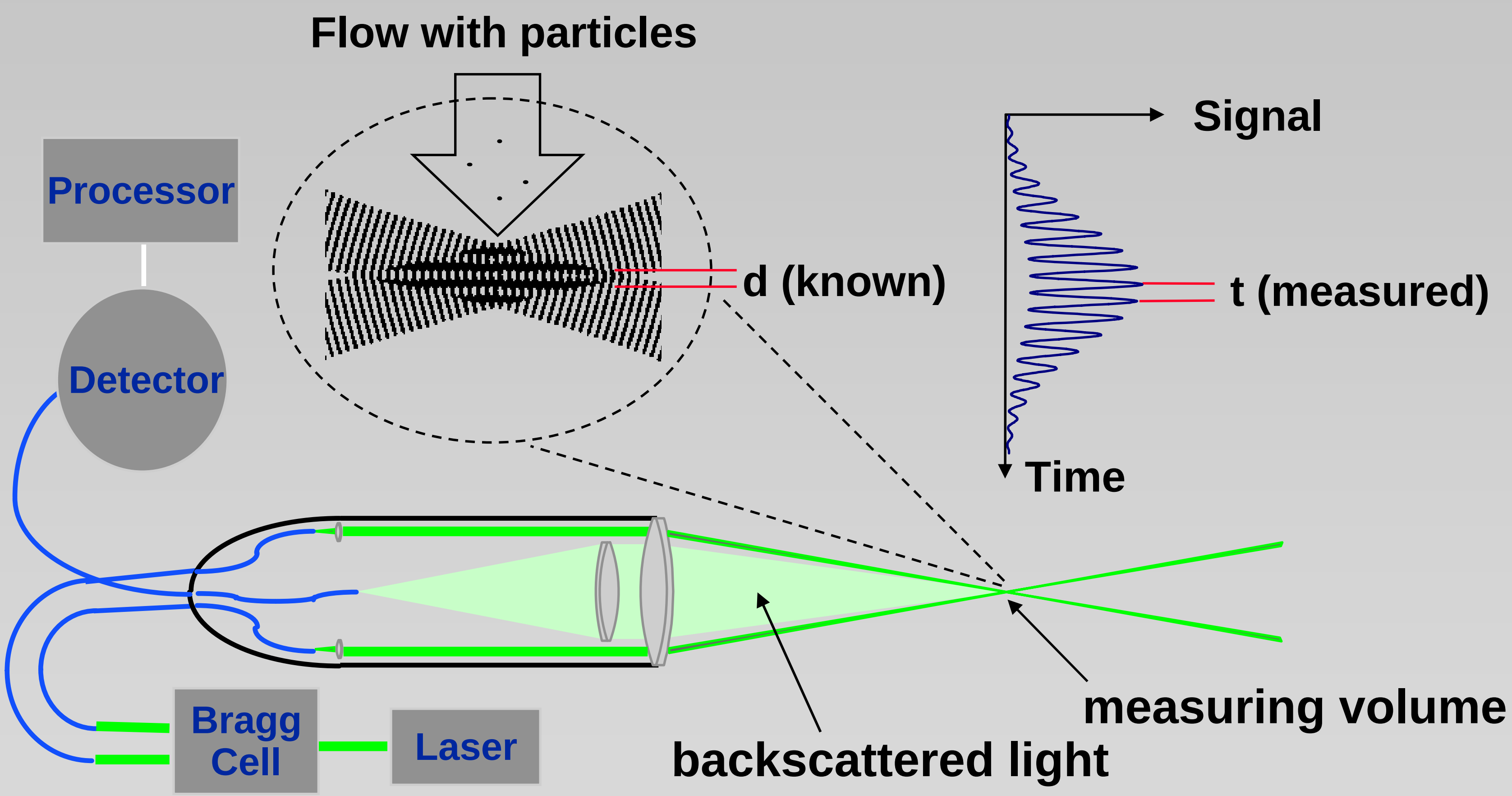
- Laminar and turbulent flows
- Investigations on aerodynamics
- Supersonic flows
- Turbines, automotive etc.
- Liquid flows
- Surface velocity and vibration measurement
- Hot environments (Flames, Plasma etc.)
- Velocity of particles
- ...... etc, etc, etc.

LDA - Fringe Model

- Focused Laser beams intersect and form the measurement volume
- Plane wave fronts: beam waist in the plane of intersection
- Interference in the plane of intersection
- Pattern of bright and dark stripes/planes



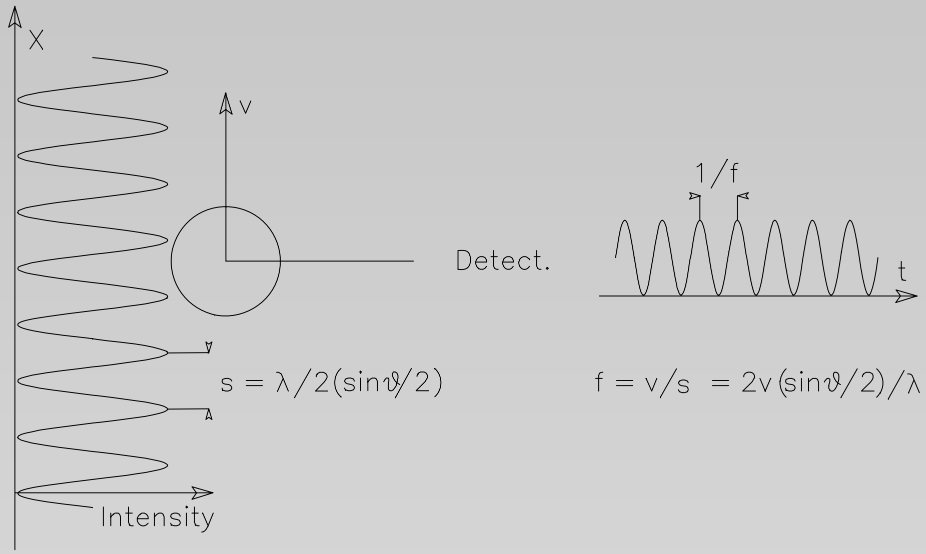
Velocity = distance/time



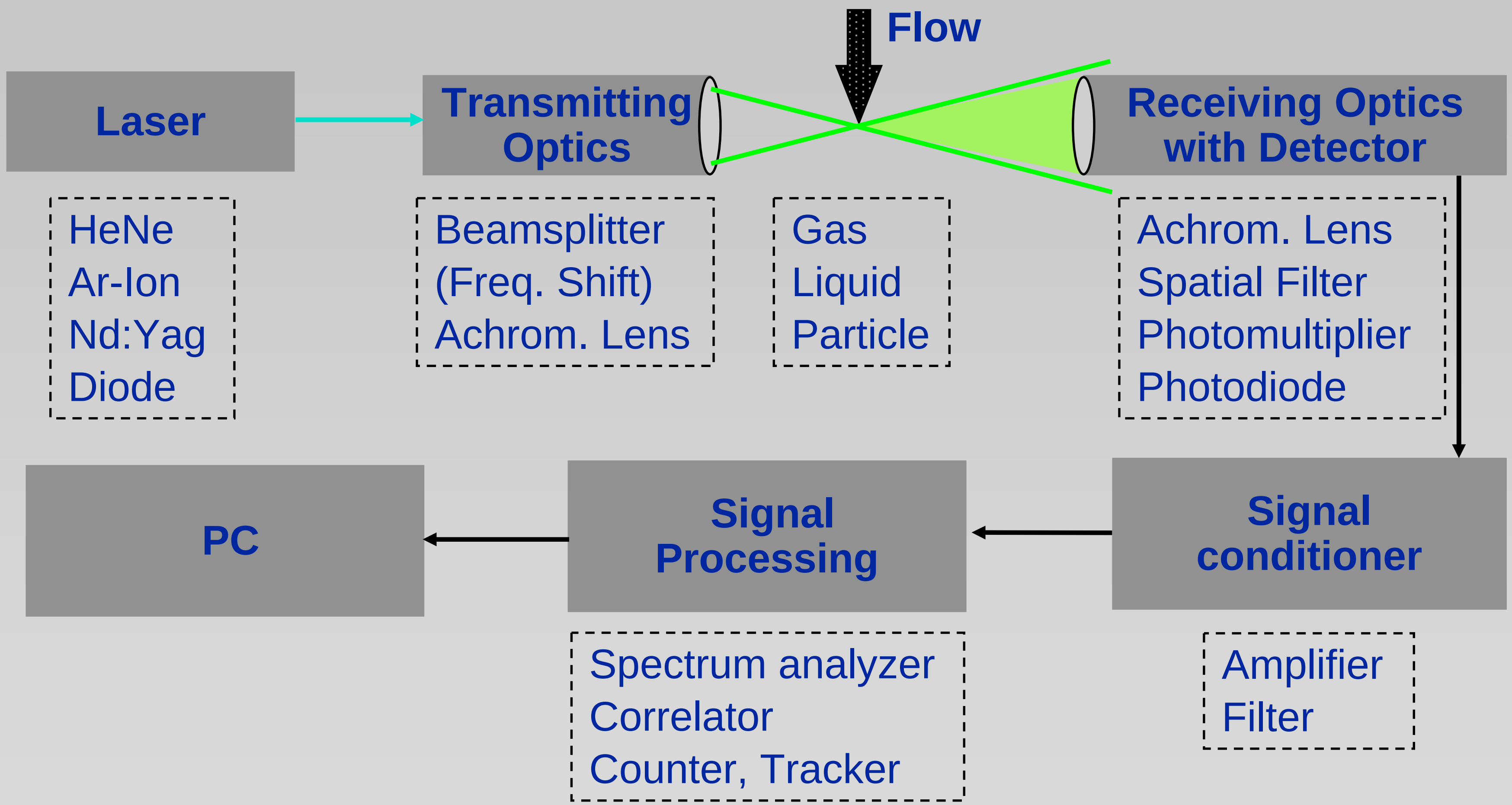
DANTEC Measurement Technology

LDA - Fringe Model

- **The fringe model assumes as a way of visualization that the two intersecting beams form a fringe pattern of high and low intensity.**
- **When the particle traverses this fringe pattern the scattered light fluctuates in intensity with a frequency equal to the velocity of the particle divided by the fringe spacing.**



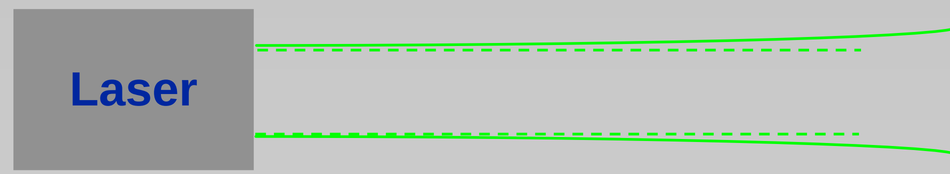
Principle of LDA

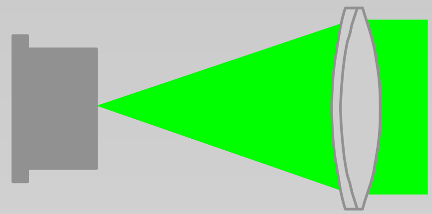


DANTEC Measurement Technology

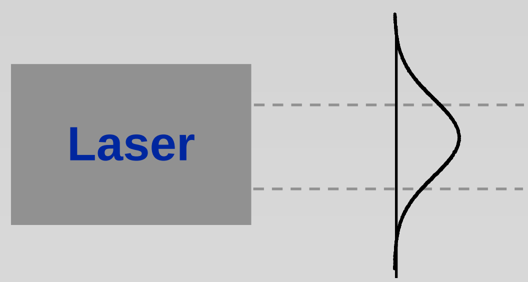
Laser, Characteristics and Requirements

- **Monochrome**
- **Coherent**
- **Linearly polarized**
- **Low divergence (collimator)**





L-Diode collimator



- **Gaussian intensity distribution**

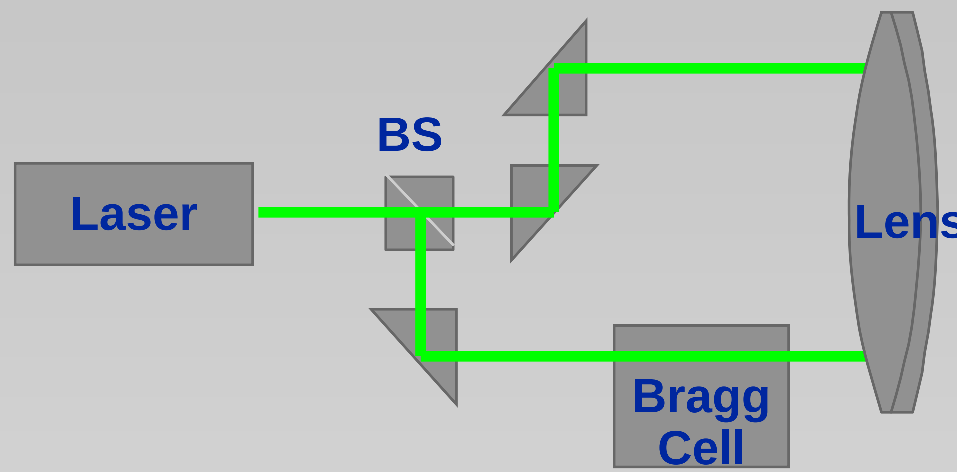
Transmitting Optics

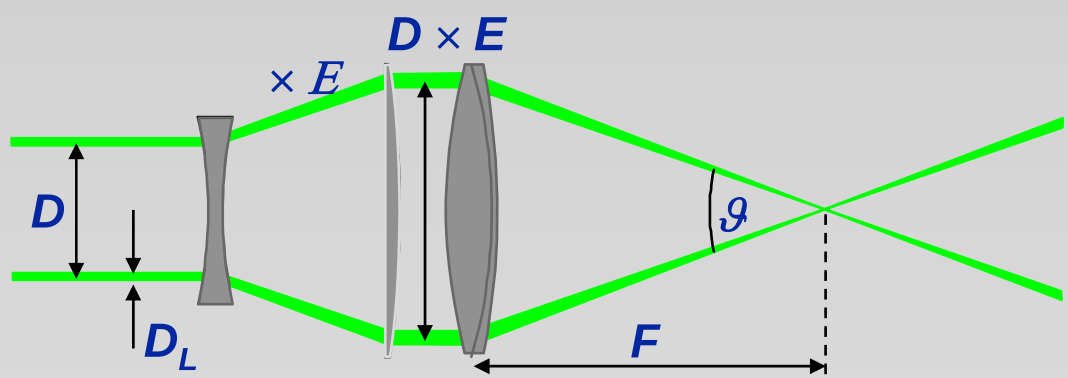
Basic modules:

- **Beam splitter**
- **Achromatic lens**

Options:

- **Frequency shift (Bragg cell)**
  - low velocities
  - flow direction
- **Beam expanders**
  - reduce measurement volume
  - increase power density

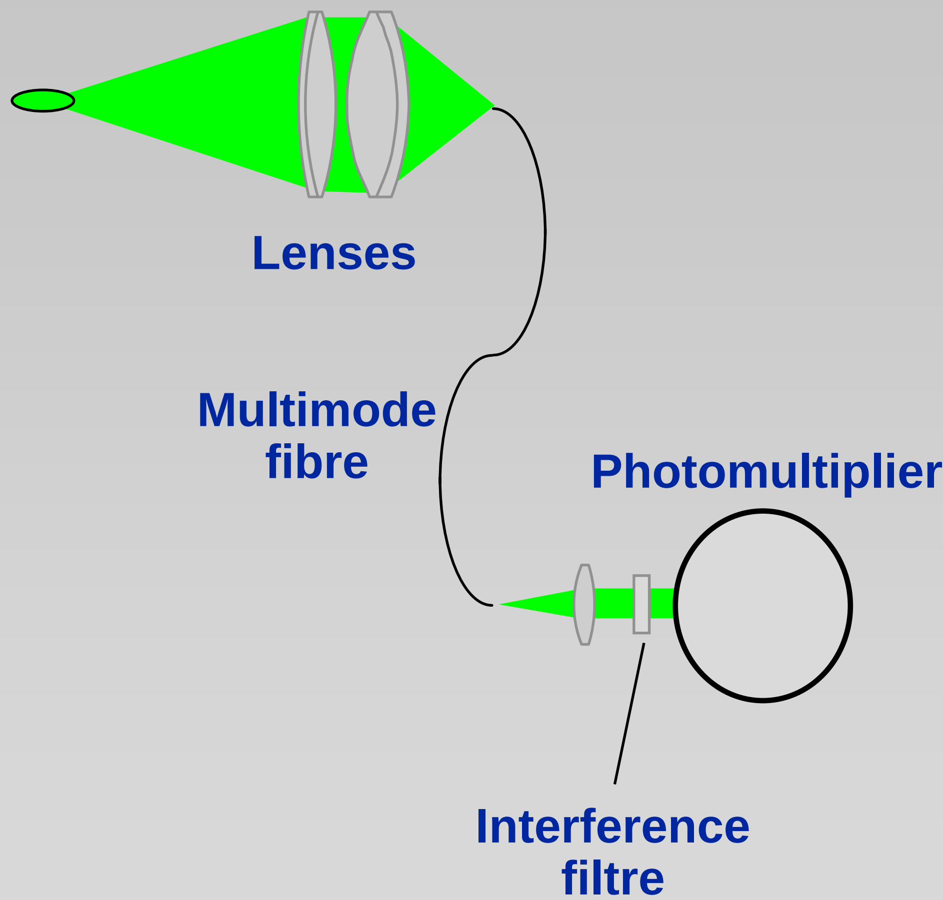




DANTEC
Measurement Technology

Receiving Systems

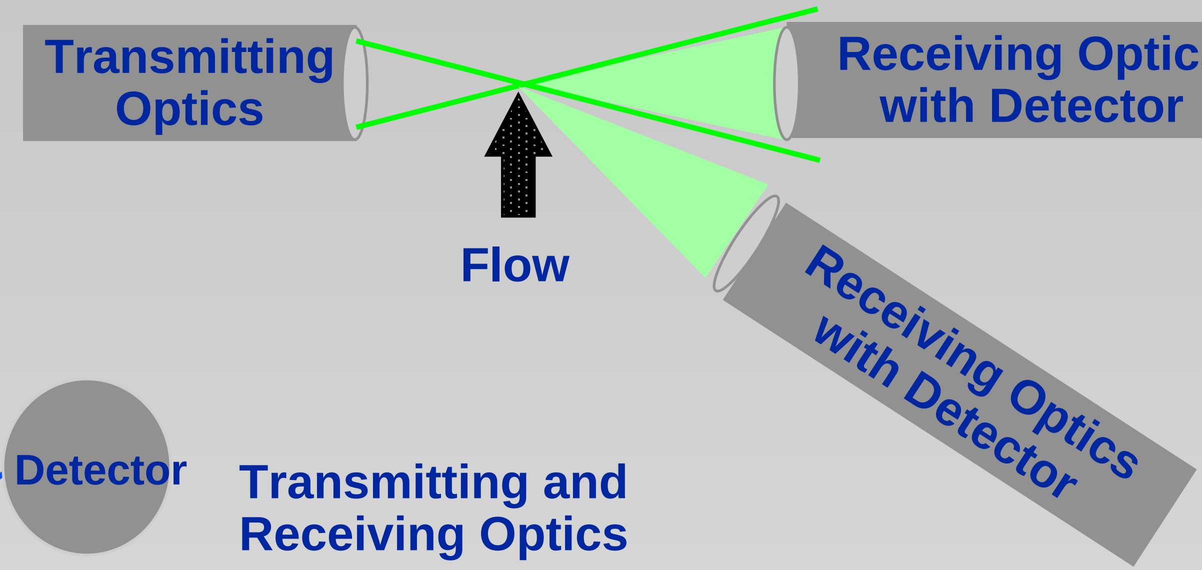
- Receiving Optics
  - Receiving optics
  - Multimode fibre acting as spatial filtre
  - Interference filtre
- Detector
  - Photomultiplier
  - Photodiode



System Configurations

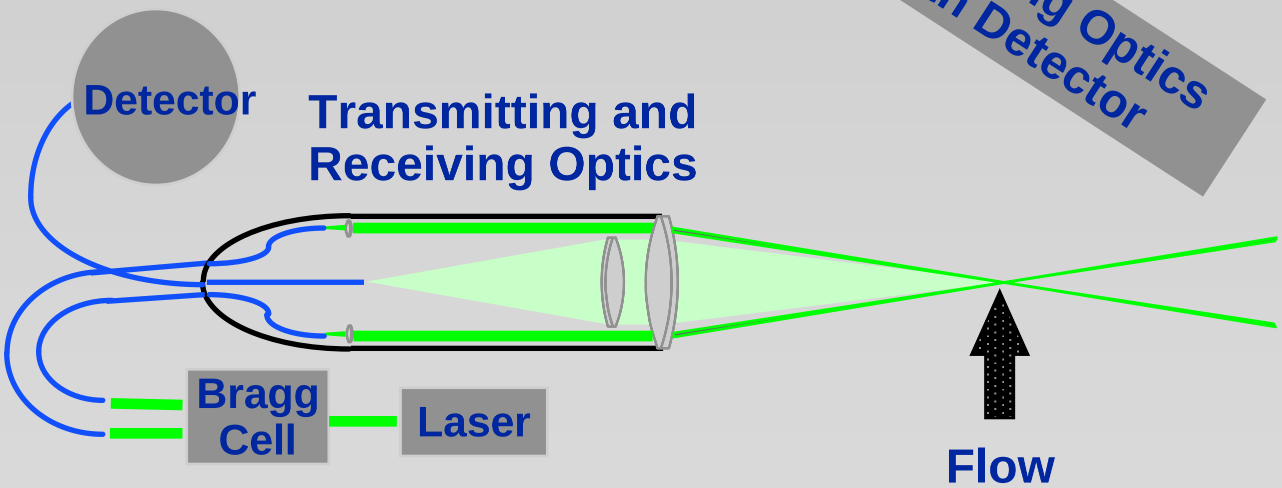
Forward scatter and side scatter (off-axis)

- Difficult to align,
- vibration sensitive

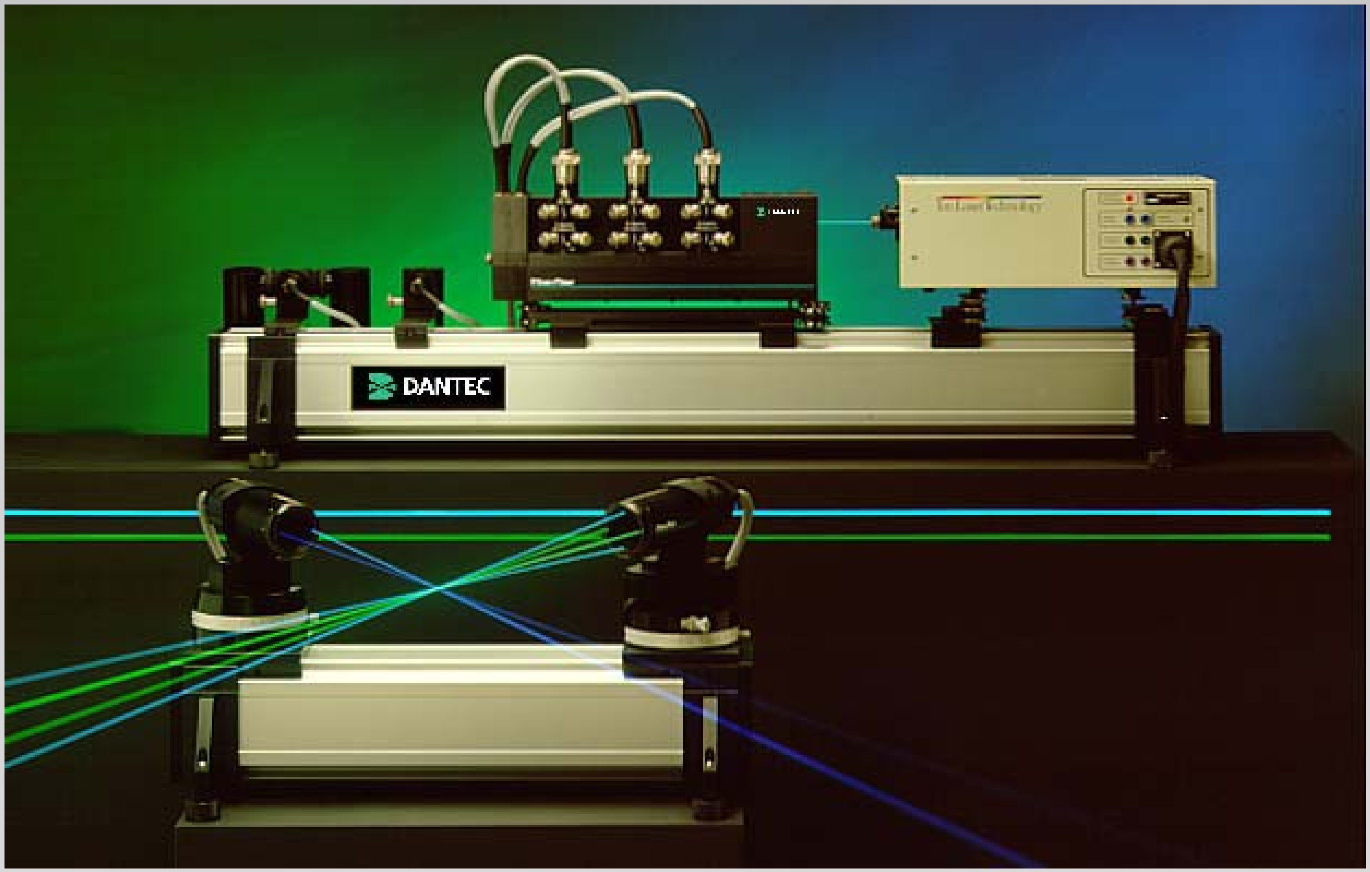


Backscatter

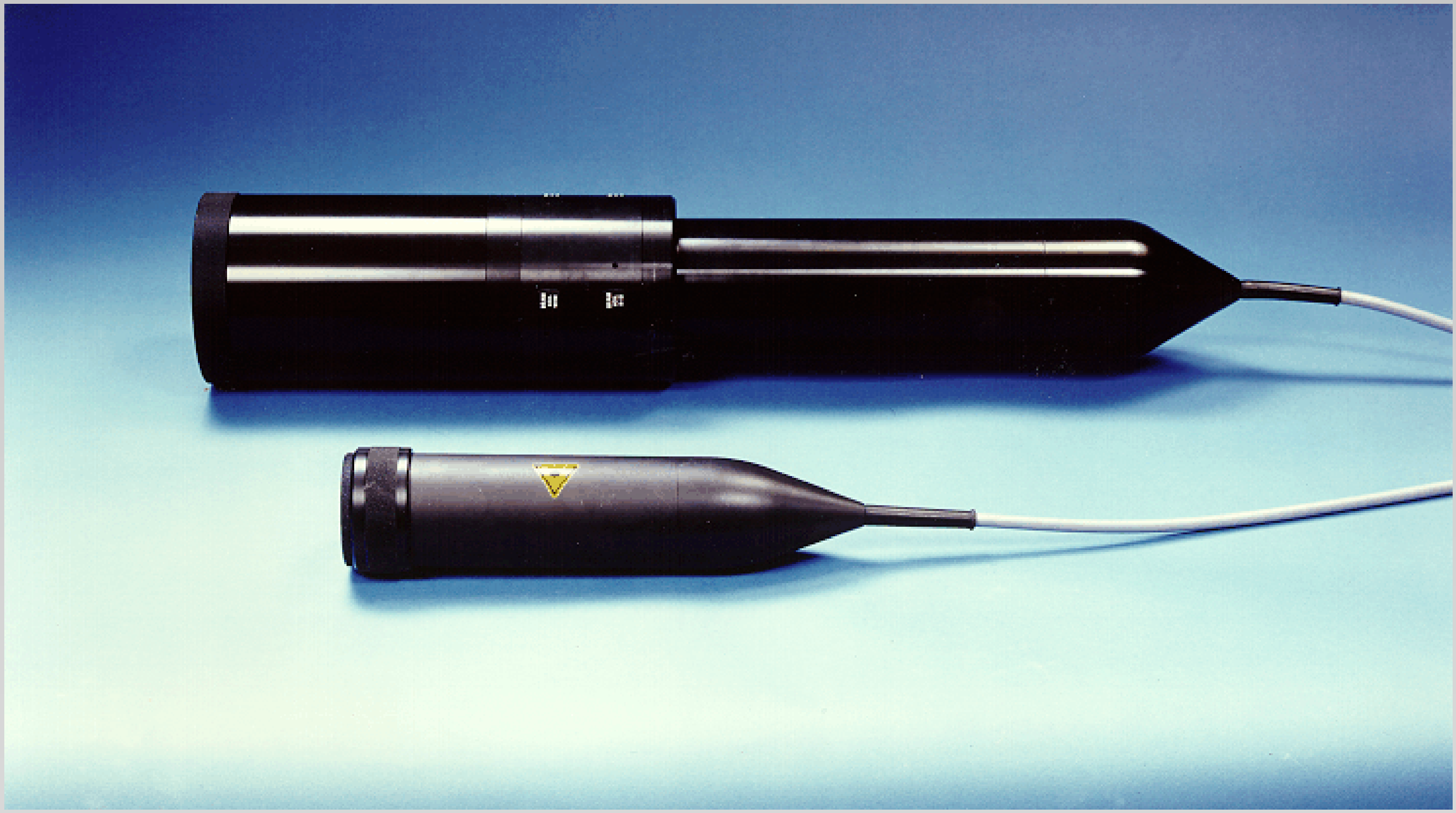
- Easy to align
- User friendly



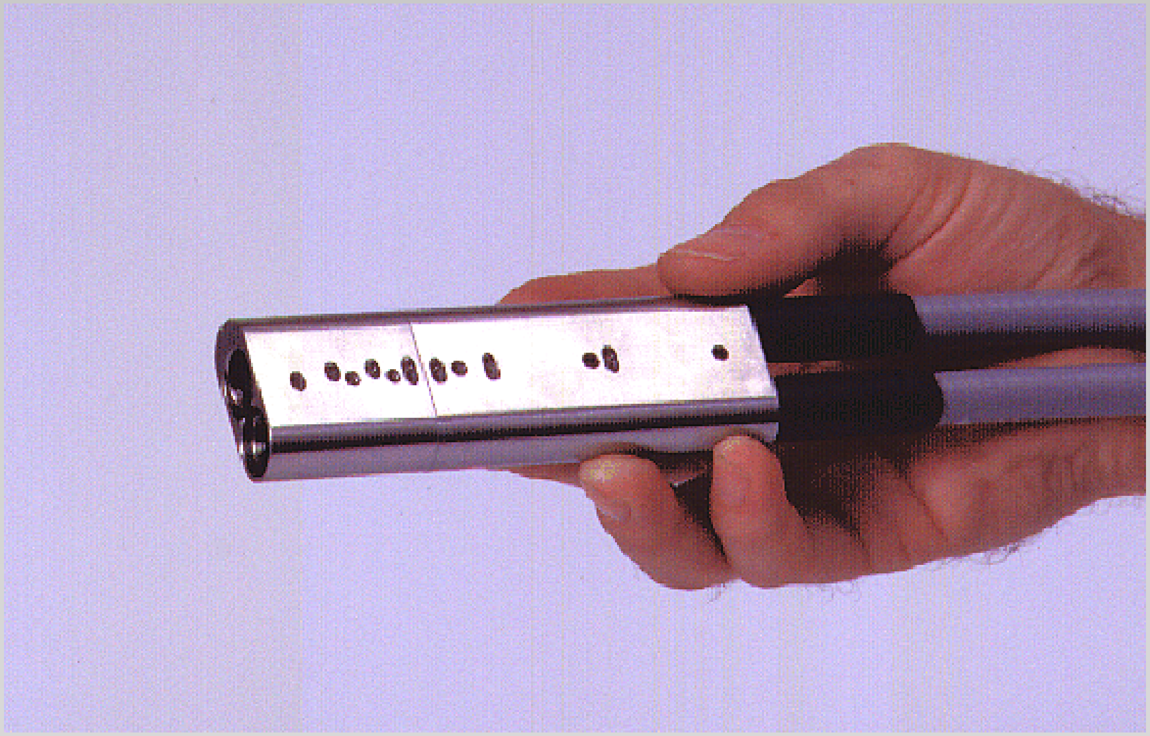
LDA Fibre Optical System



60 mm and 85 mm *FiberFlow* probes



The small integrated 3D *FiberFlow* probe



3-D LDA Applications

- Measurements of boundary layer separation in wind tunnels
- Turbulent mixing and flame investigations in combustors
- Studies of boundary layer-wake interactions and instabilities in turbines
- Investigations of flow structure, heat transfer, and instabilities in heat exchangers
- Studies of convection and forced cooling in nuclear reactor models
- Measurements around ship models in towing tanks

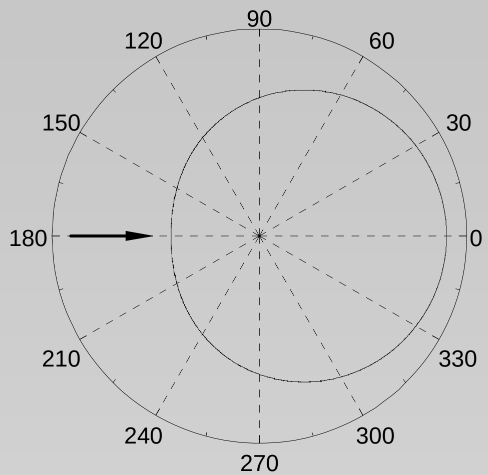
Seeding: ability to follow flow

Particle Frequency Response

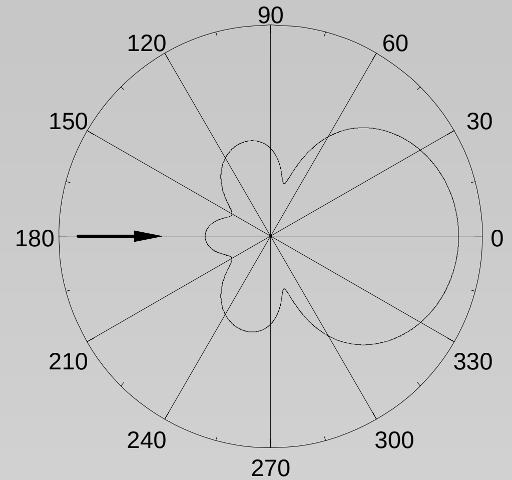
$$\frac{d}{dt} U_p = -18 \frac{\nu}{d_p^2} \frac{U_p - U_f}{\rho_p / \rho_f}$$

Particle	Fluid	Diameter (μm) f = 1 kHz	Diameter (μm) 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

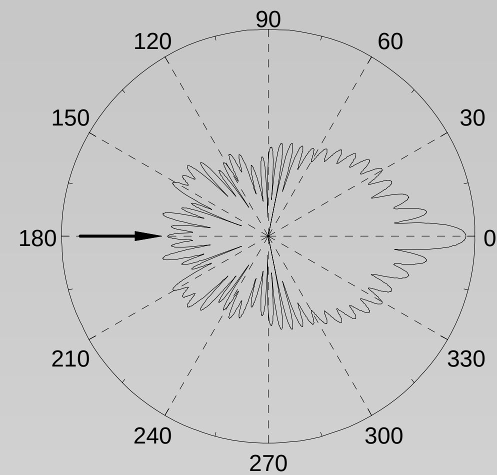
Seeding: scattered light intensity



$d_p \cong 0.2\lambda$



$d_p \cong 1.0\lambda$



$d_p \cong 10\lambda$

- **Polar plot of scattered light intensity versus scattering angle**
- **The intensity is shown on a logarithmic scale**

Measurement of air flow around a helicopter rotor model in a wind tunnel

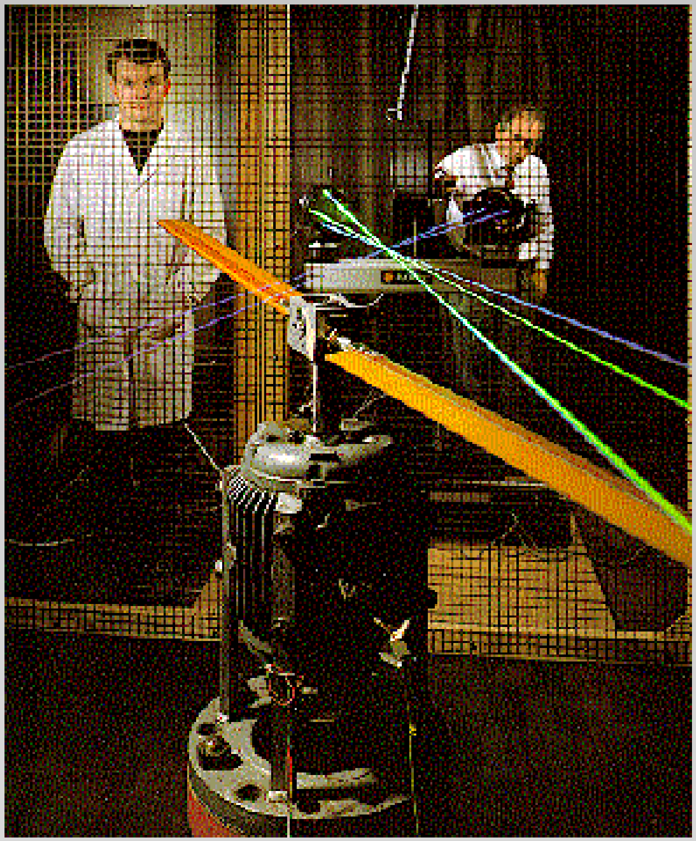


Photo courtesy of University of Bristol, UK

DANTEC Measurement Technology

Measurement of water flow inside a pump model

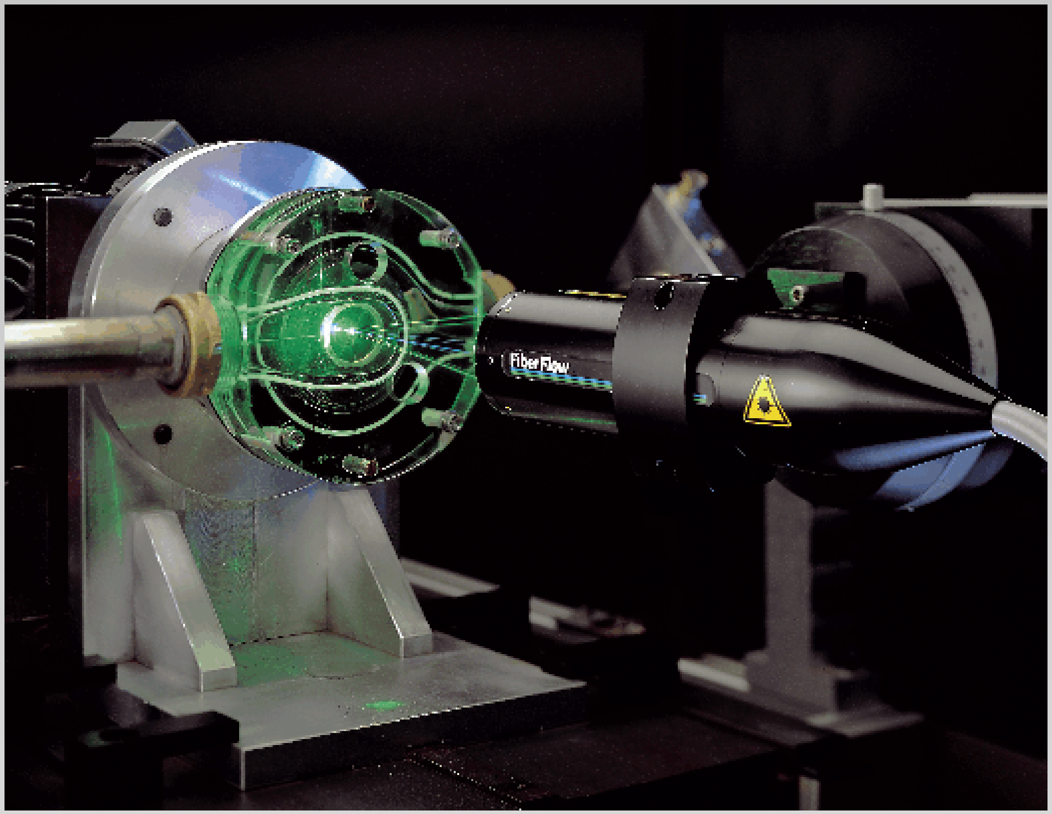
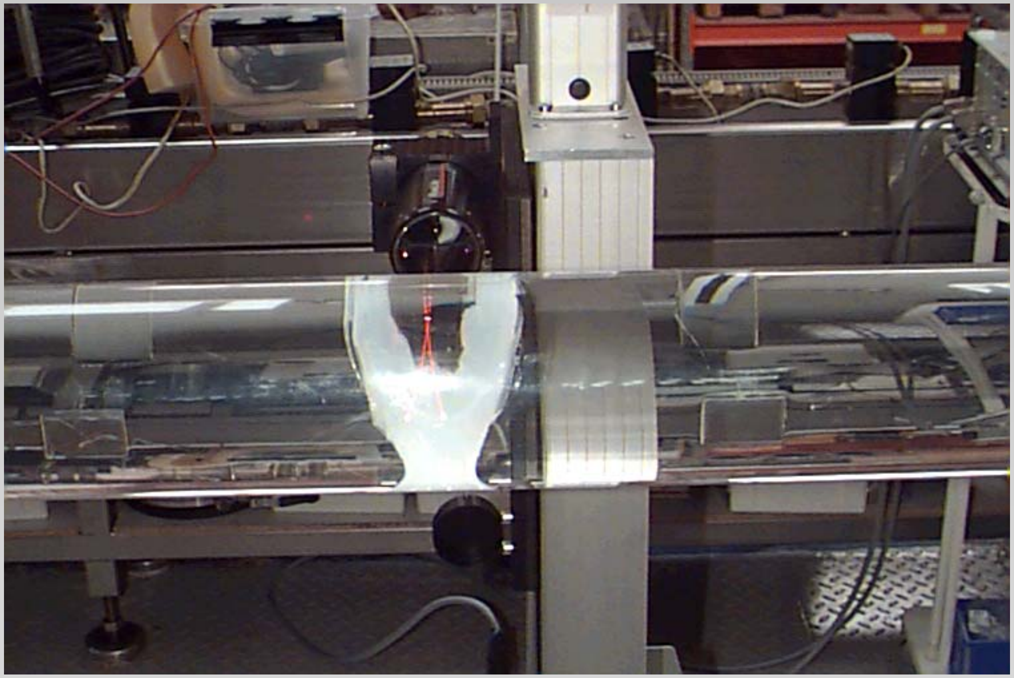


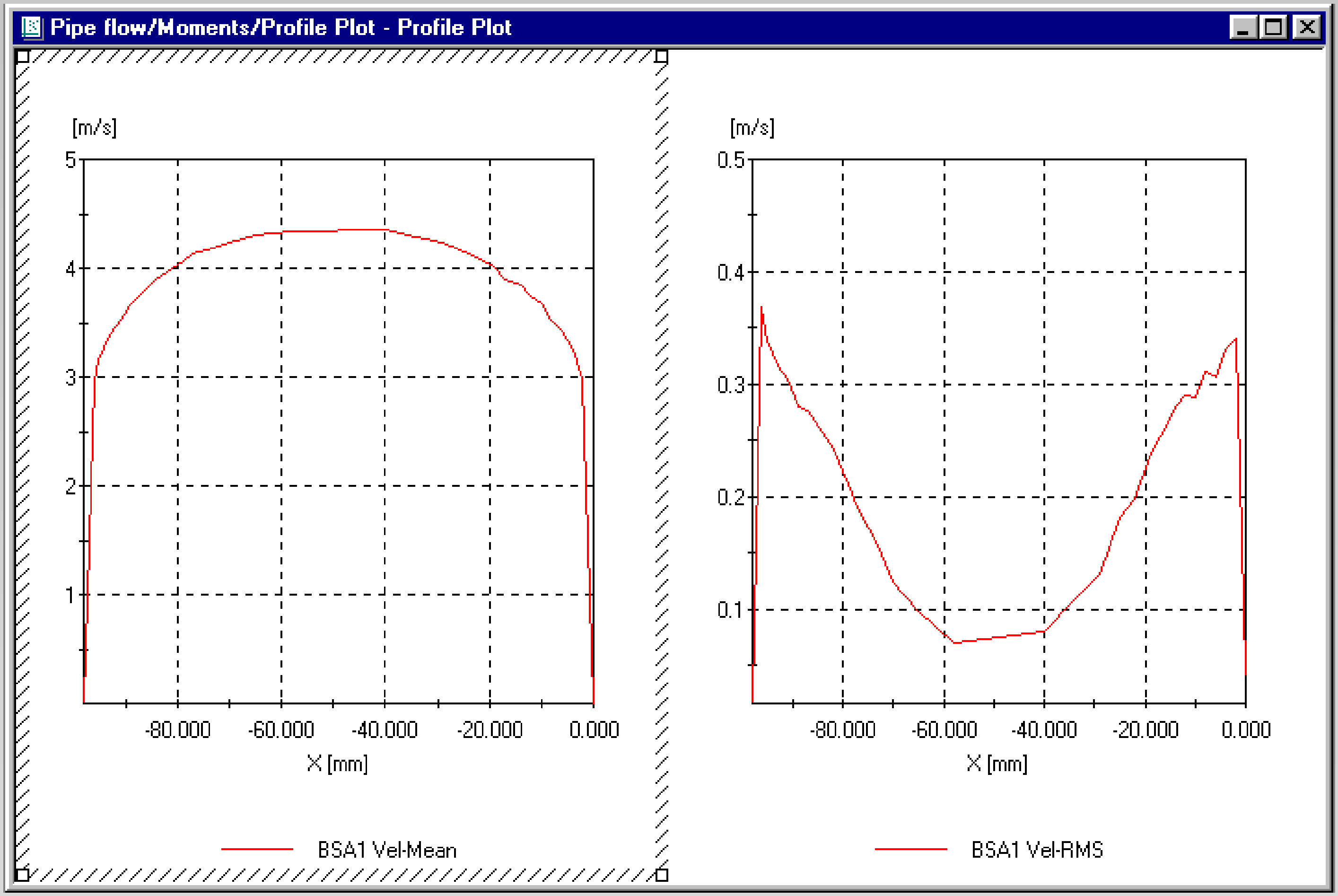
Photo courtesy of Grundfos A/S, DK

DANTEC
Measurement Technology

Measurement of velocity profiles in a water pipe



Velocity profile, fully developed turbulent pipe flow



Measurement of flow field around a 1:5 scale car model in a wind tunnel

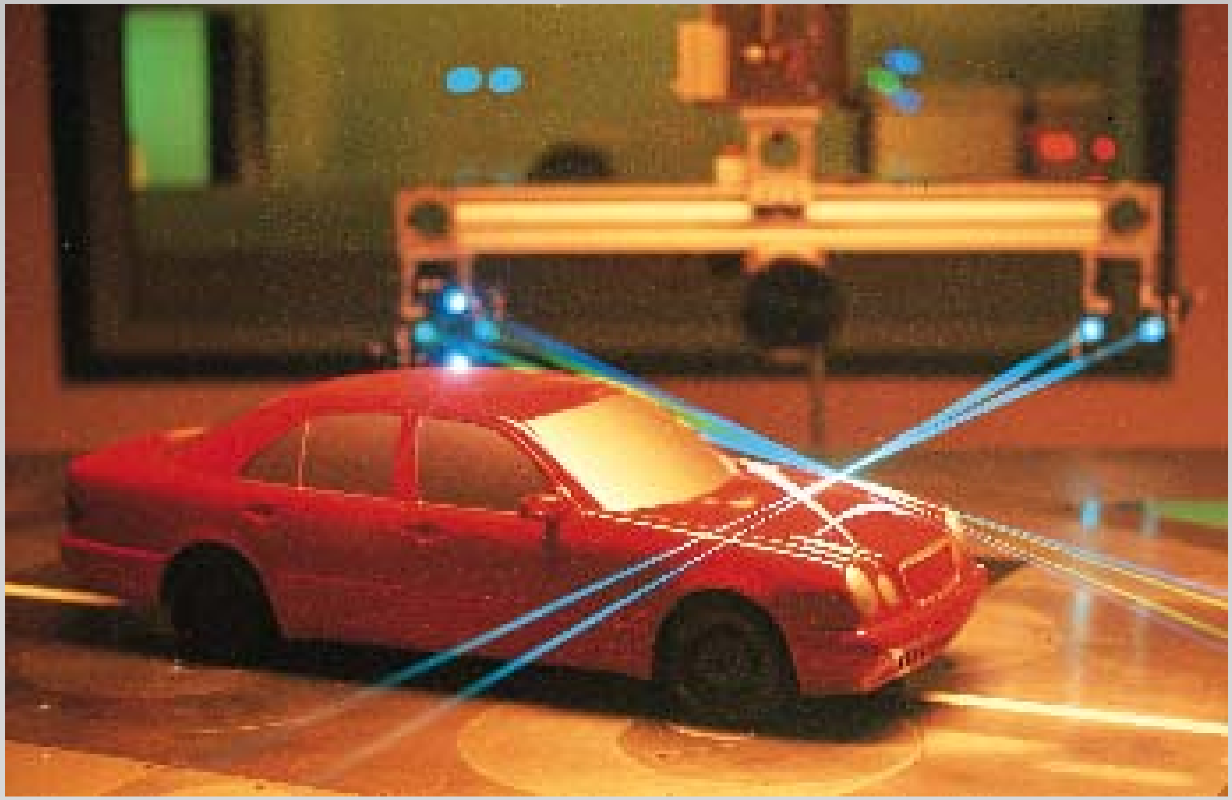


Photo courtesy of Mercedes-Benz, Germany

DANTEC
Measurement Technology

Measurement of wake flow around a ship model in a towing tank

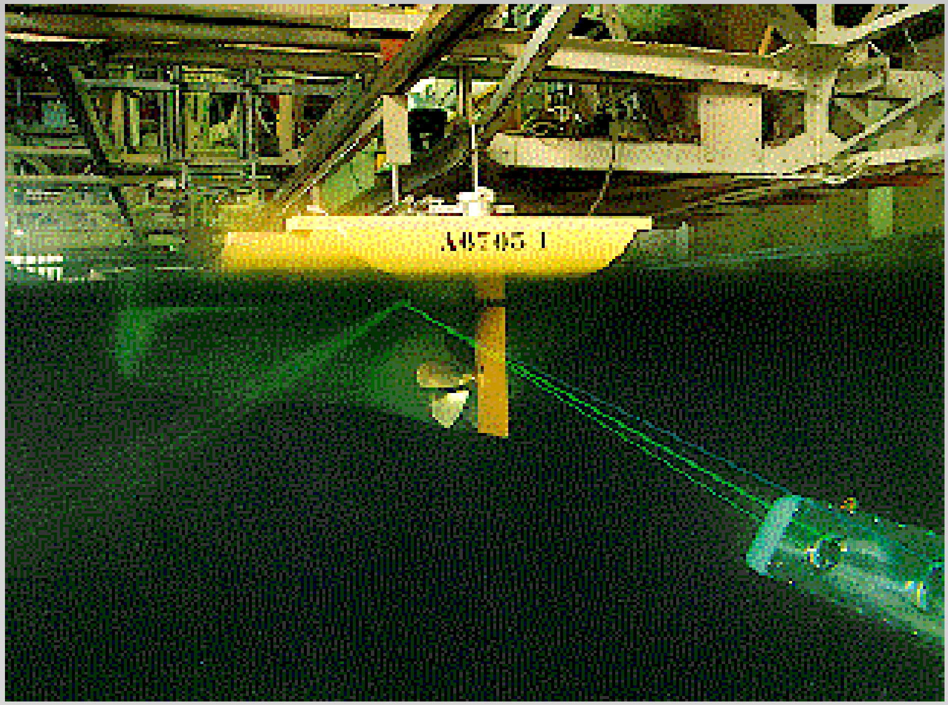


Photo courtesy of Marin, the Netherlands

DANTEC
Measurement Technology

Measurement of air flow field around a ship model in a wind tunnel

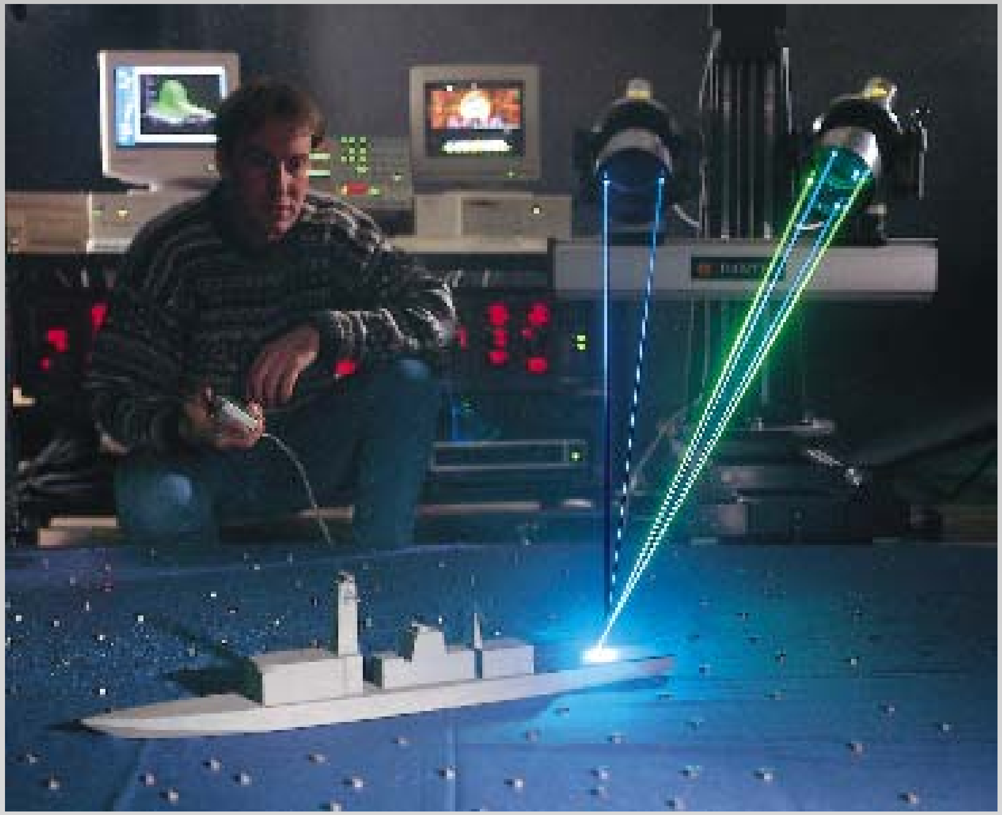
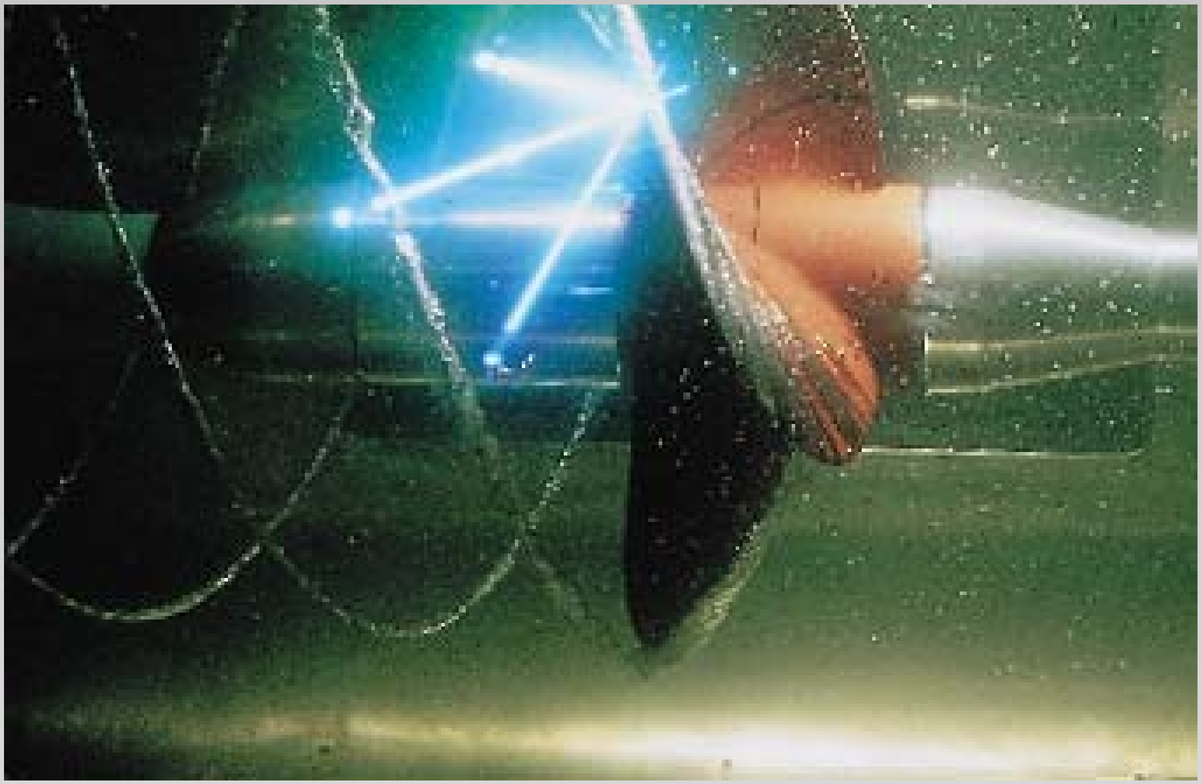


Photo courtesy of University of Bristol, UK

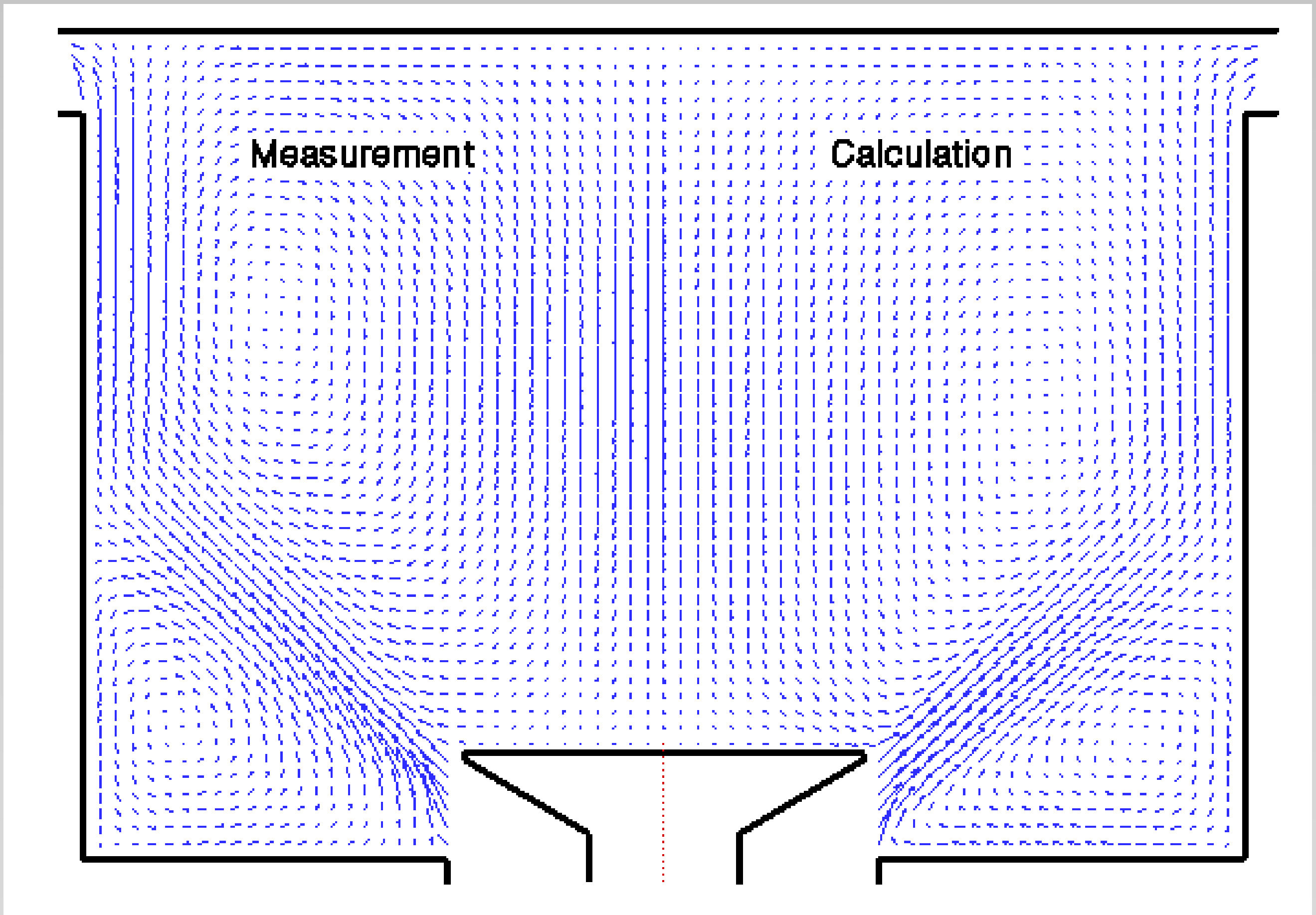
DANTEC Measurement Technology

Measurement of flow around a ship propeller in a cavitation tank



DANTEC
Measurement Technology

Comparison of EFD and CFD results



DANTEC
Measurement Technology