Lecture 13: Laser Doppler Velocimetry (LDV) & Global Doppler Velocimetry (GDV) - Part 02

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❑ Fundamentals of LDV

- *By using a laser bean of wavelength λ=488nm (Argon-Ion laser), the maximum Doppler shift from a particle moving with a velocity of V would be:*
  - *V=1.0m/s $\Delta f \approx$ 4.1 MHz*
  - *V=10.0m/s $\Delta f \approx$ 41 MHz*
  - *V=100.0m/s $\Delta f \approx$ 410 MHz*
  - *V=1000m/s $\Delta f \approx$ 4100 MHz*

$$\Delta f = f_r - f = \frac{V_\phi \cdot 2\sin(\frac{\phi}{2}) f}{f\lambda} = \frac{V_\phi \cdot 2\sin(\frac{\phi}{2})}{\lambda}$$

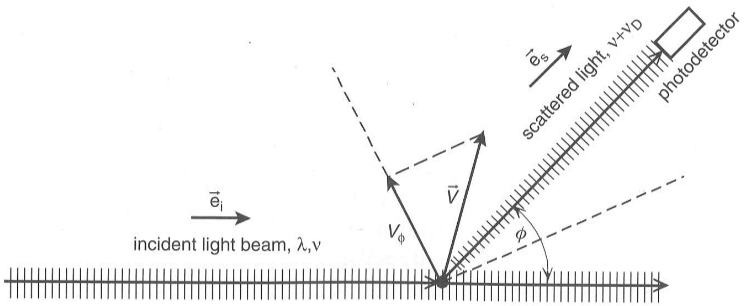


Figure 11.9. Sketch of a laser beam light scattered by a moving particle.

- *However, since C = 2.998×10^8 m/s, λ=488nm, then, f=c/λ= 1.4 ×10^9 MHz. the Doppler shift in frequency is very small compared with the frequency of the source laser light.*
- *In practice, it is always quit difficult to measure the Doppler shift of frequency accurately for low-speed flows by measuring the received total frequency directly.*

- *Dual-beam LDV technique was developed to measure the relative frequency change due to the Doppler shift other than the total frequency.*

❑ Generated Fringes for the Dual-Beam LDV

Fring spacing : $\delta = \dfrac{\lambda}{2\sin(\theta/2)}$

Fring number : $N = \dfrac{4}{\pi}\dfrac{D_T}{d_e};$

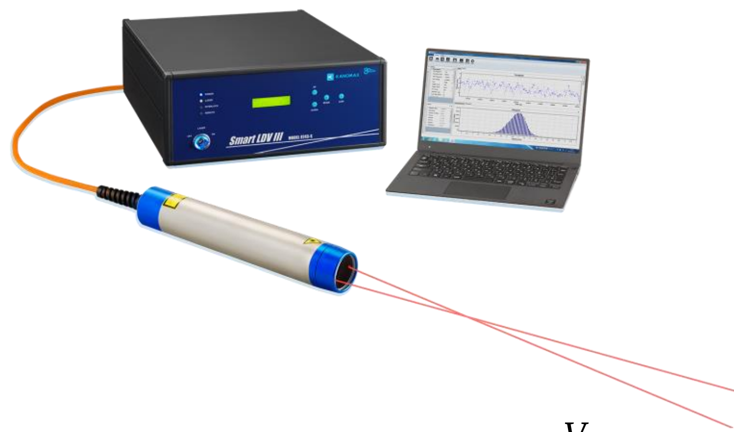
$D_T = 2 f_T \sin(\theta/2)$

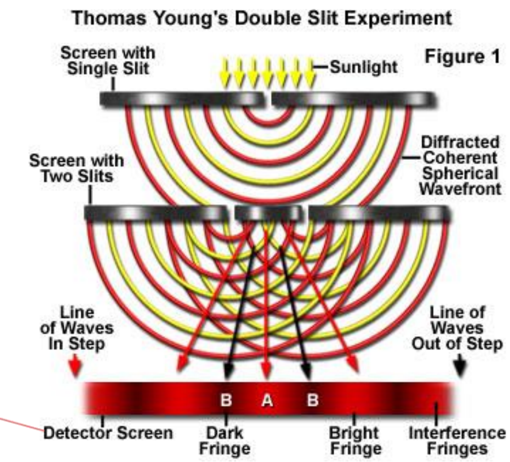
Frequency of the scattering light :

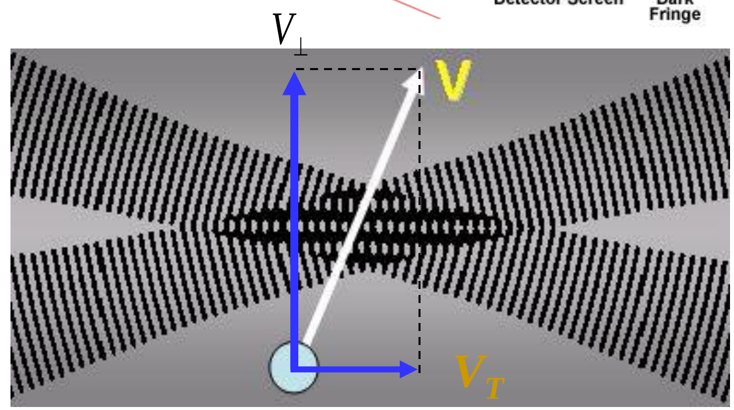
$$f = \frac{V_\perp}{\delta} = \frac{2\sin(\theta/2)}{\lambda} V_\perp$$

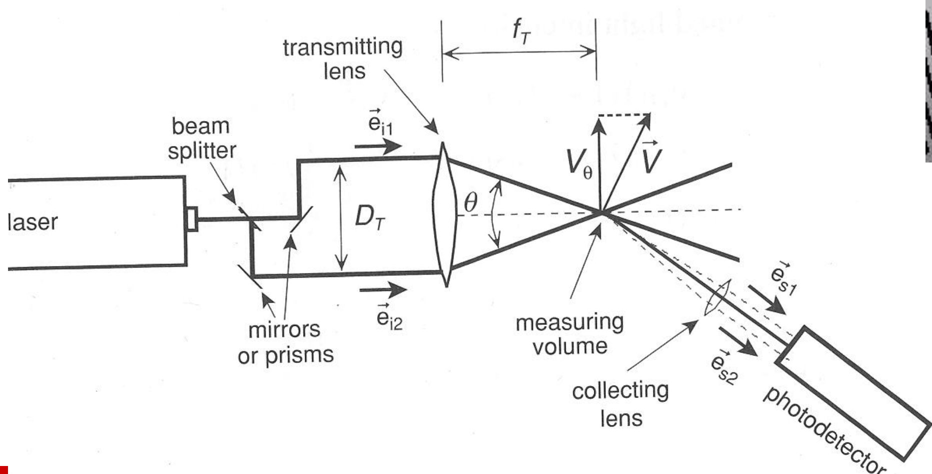
Frequency shift according to Doppler shift theo ry :

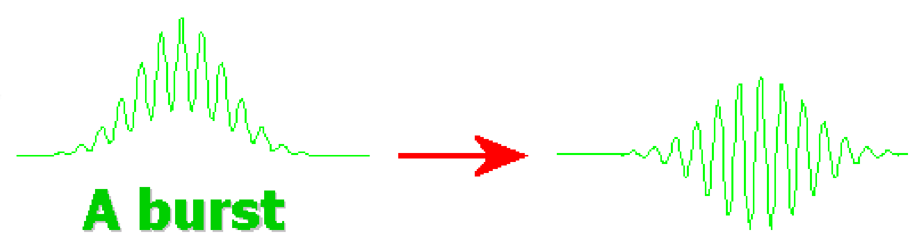
$$f = \frac{2\sin(\theta/2)}{\lambda} V_\perp$$







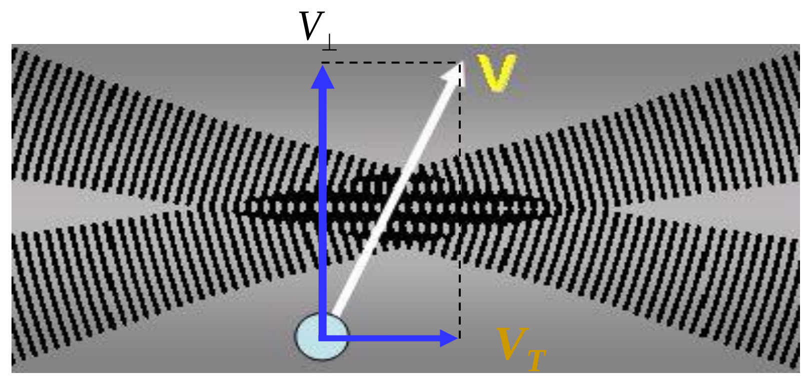




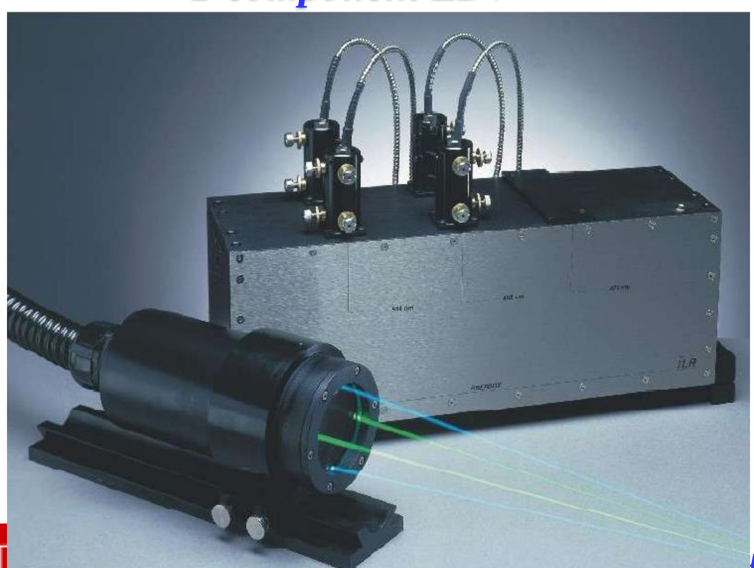
❑ 2-COMPONENT LDV SYSTEMS

- *Dual-beam laser setup only can measure one component of the velocity with its direction normal to the fringe planes.*

- *Two-color LDV system can be used for 2-components of flow velocity measurements.*
  - *Ar-ion Laser beams*
    - *Blue (488nm)*
    - *Yellow (514.5 nm)*

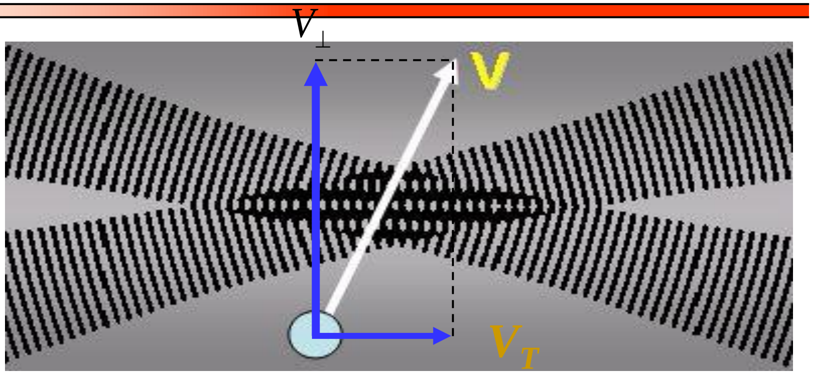


2-component LDV

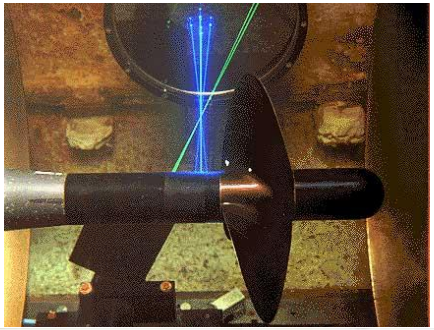


❑ 3-COMPONENT LDV SYSTEMS

- Dual-beam laser setup only can measure one component of the velocity with its direction normal to the fringe planes.

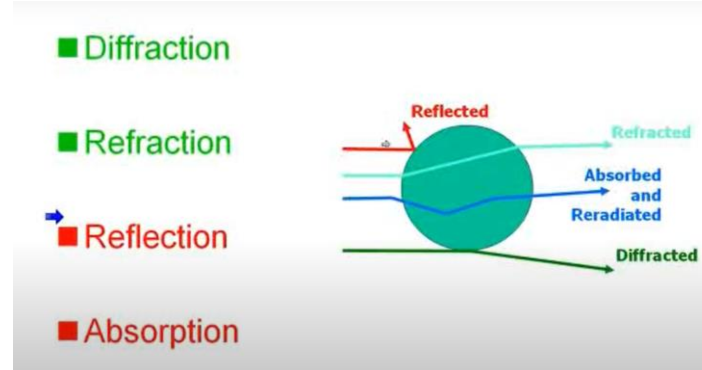


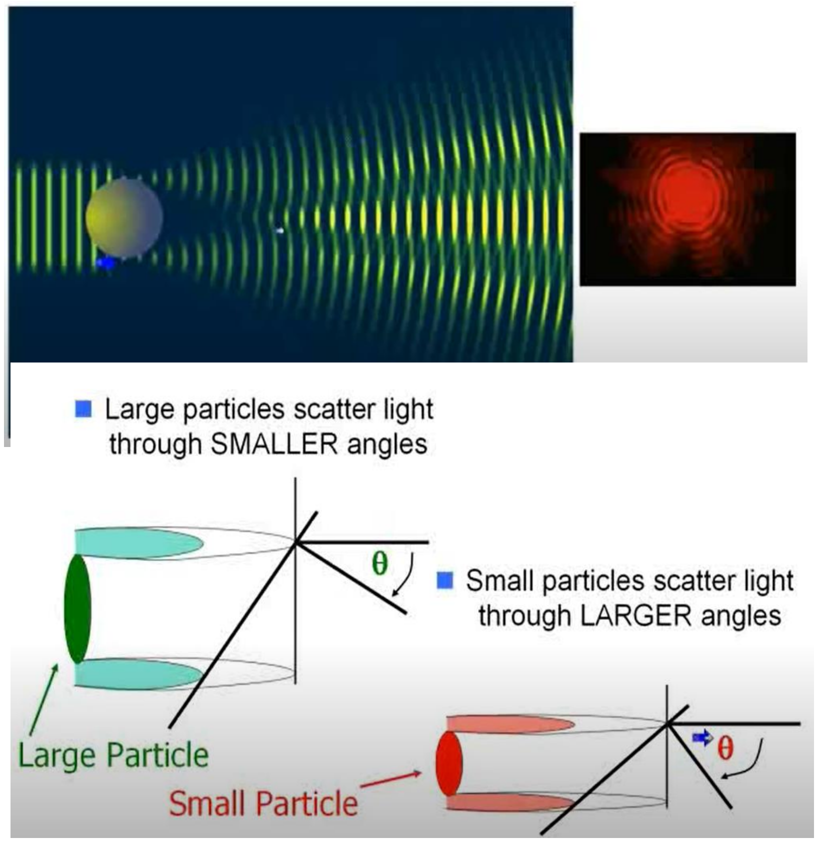
- Two-color LDV system can be used for 2-components of flow velocity measurements.
    - Ar-ion Laser beams
        - Blue (488nm)
        - Yellow (514.5 nm)
        - Purple (476.4nm)

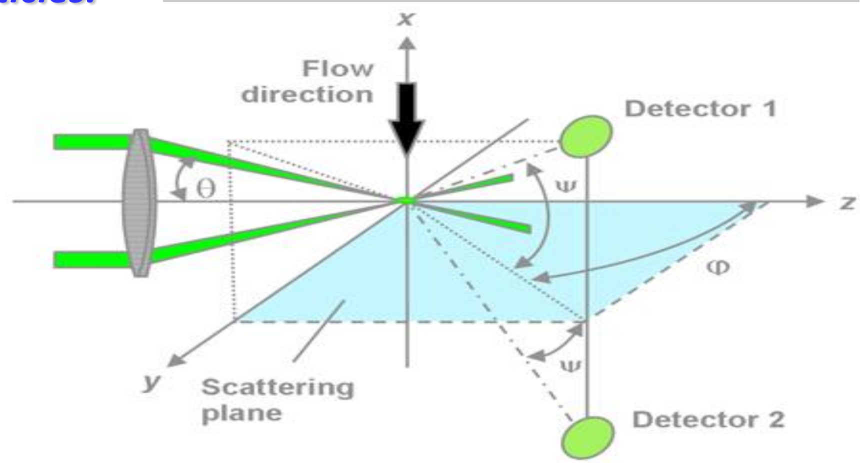


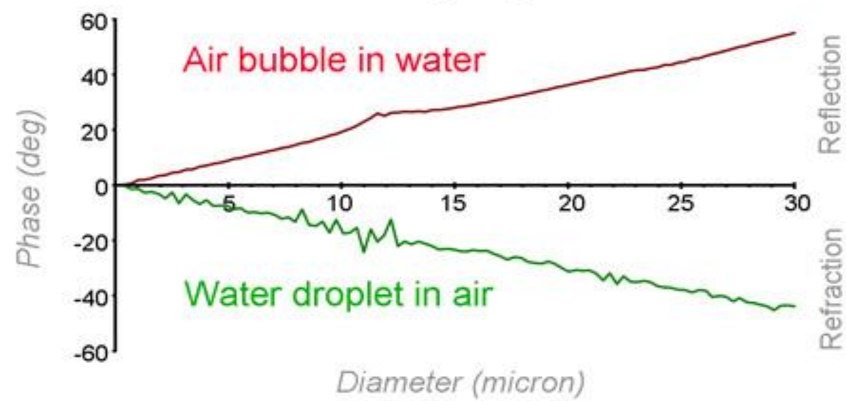
❑ Phase Doppler Particle Analyzers/PDPA Systems

- *As particles pass through the probe volume, they scatter light from the beams and create an interference fringe pattern.*
- *A receiving lens at an off-axis collection angle projects part of this fringe pattern onto detectors to produce a Doppler burst signal with a frequency proportional to the particle velocity.*
- *The phase shift between the Doppler burst signals from the detectors is proportional to the size of the spherical particles.*

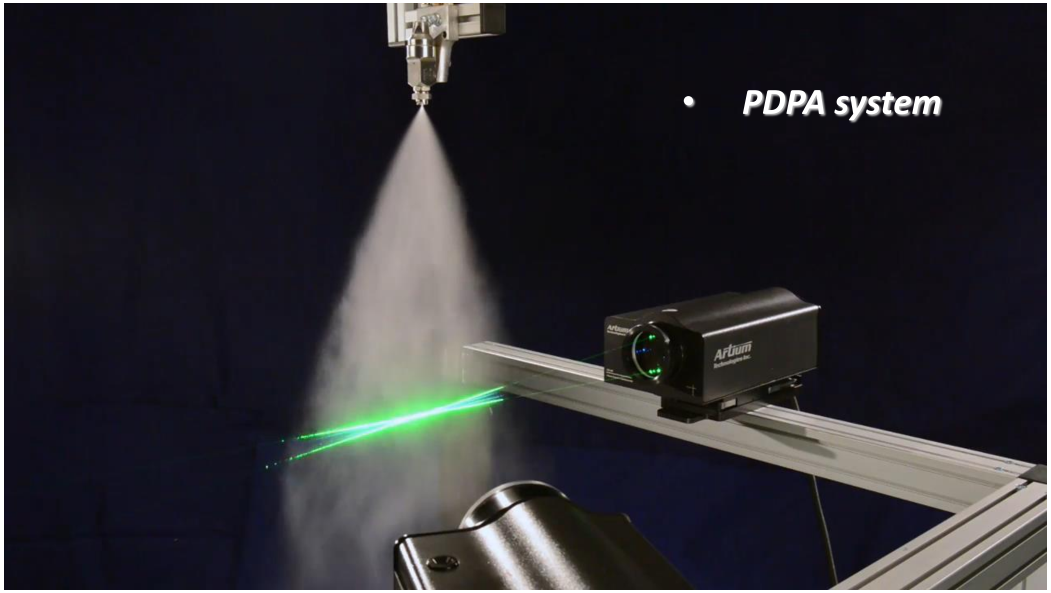


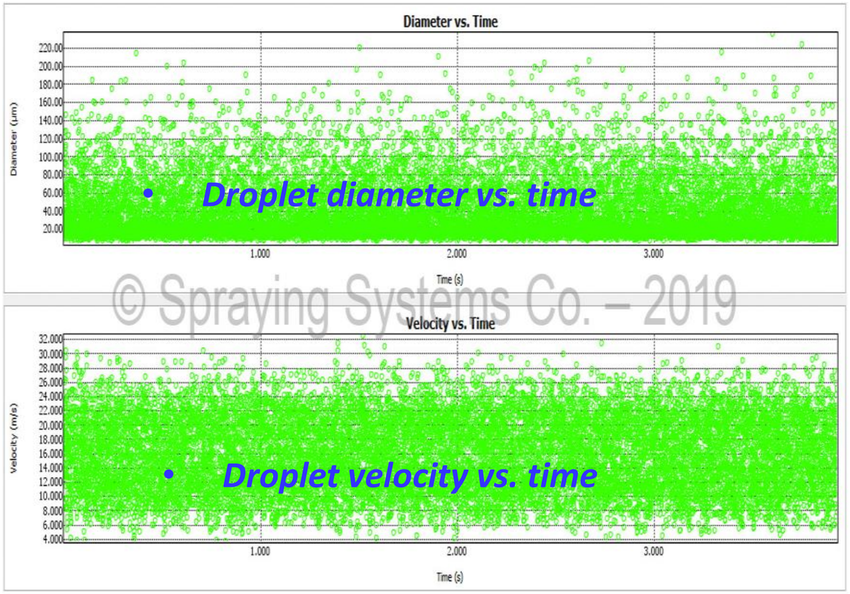


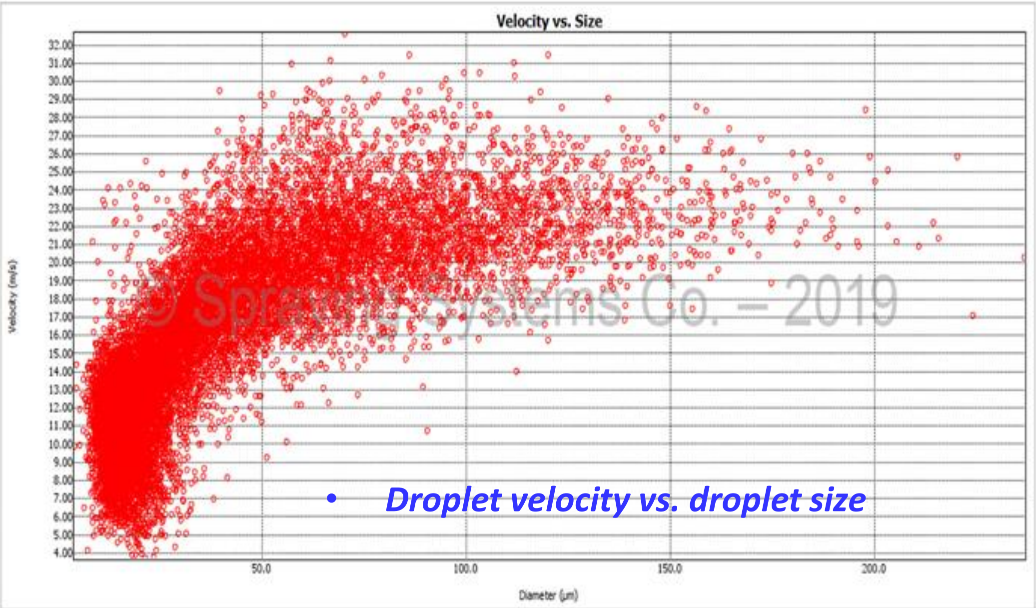


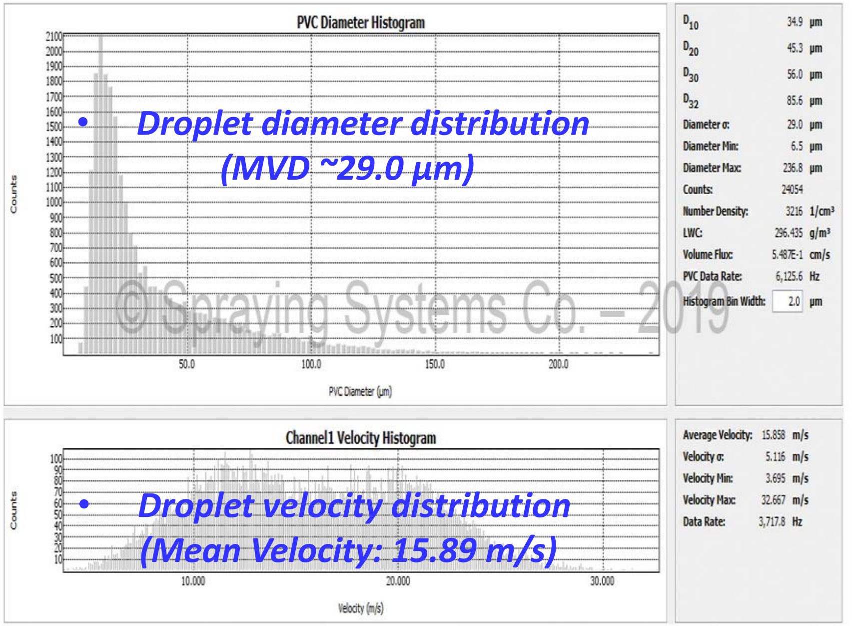


❑ Phase Doppler Particle Analyzers/PDPA Systems



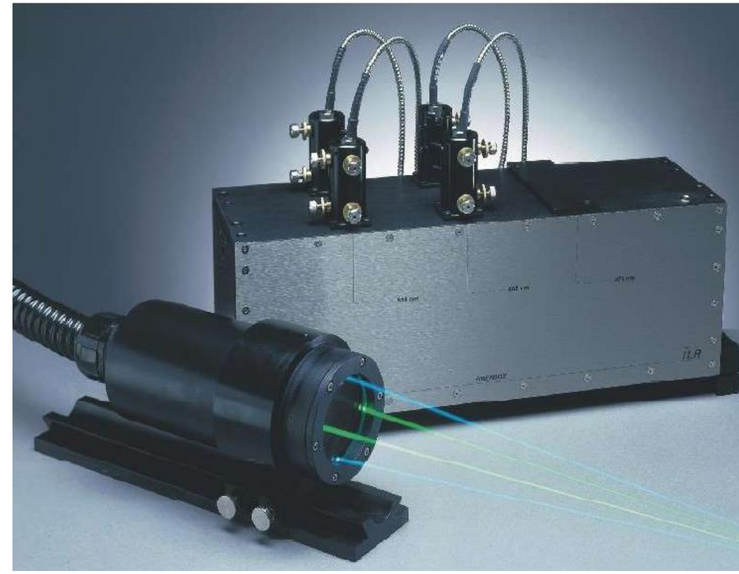


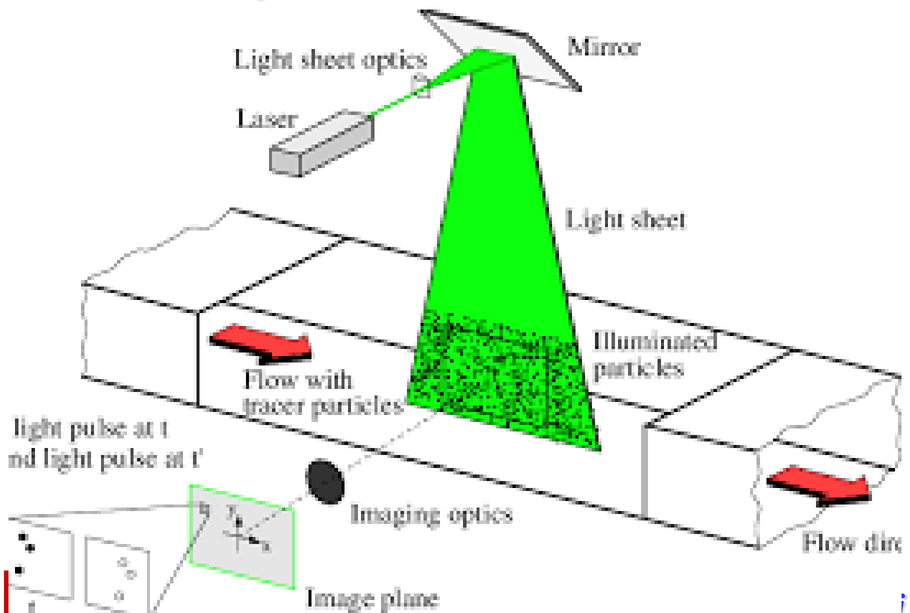


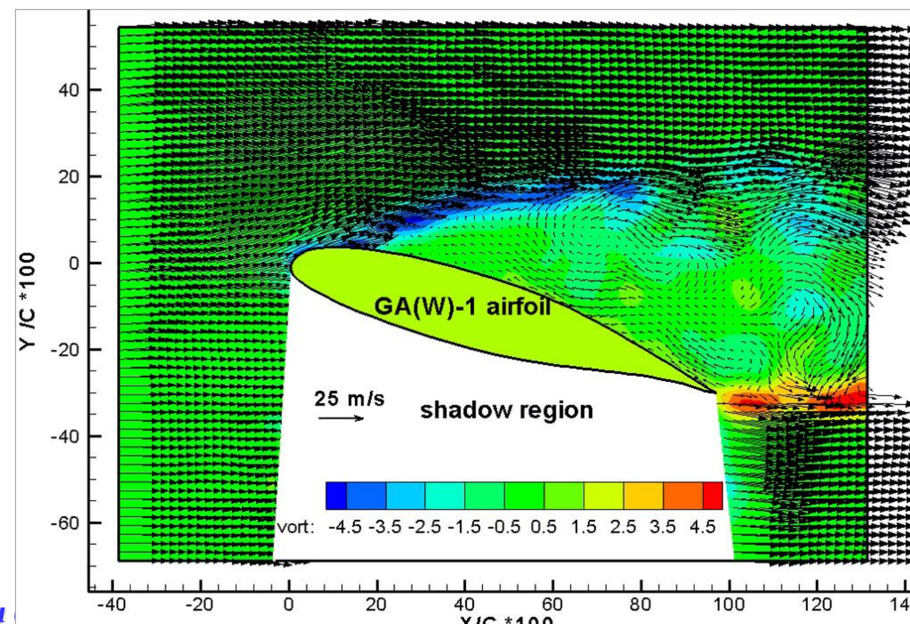


❑ Advantages and disadvantages of LDV technique

- *Advantages:*
  - *Non-intrusive*
  - *High resolution*
  - *High accuracy*
  - *Wide dynamic range of measurements*
- *Disadvantages*
  - *Single point measurements*
  - *Expansive in instrumentation*

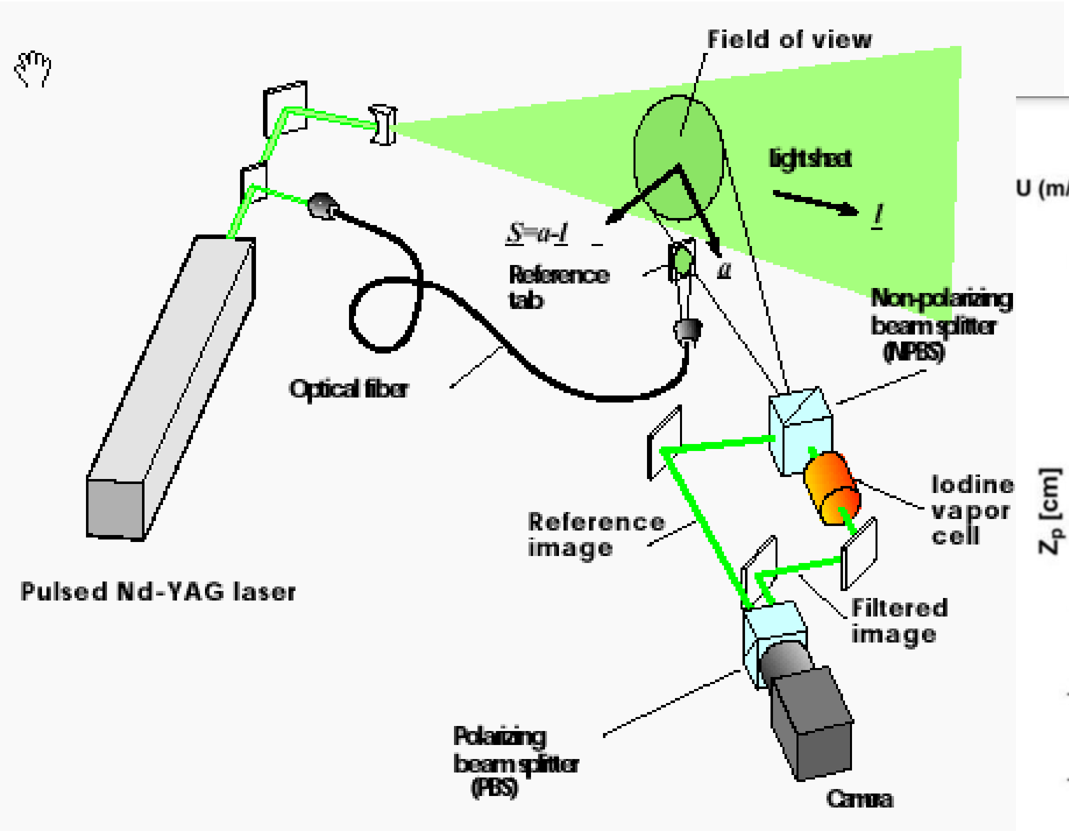


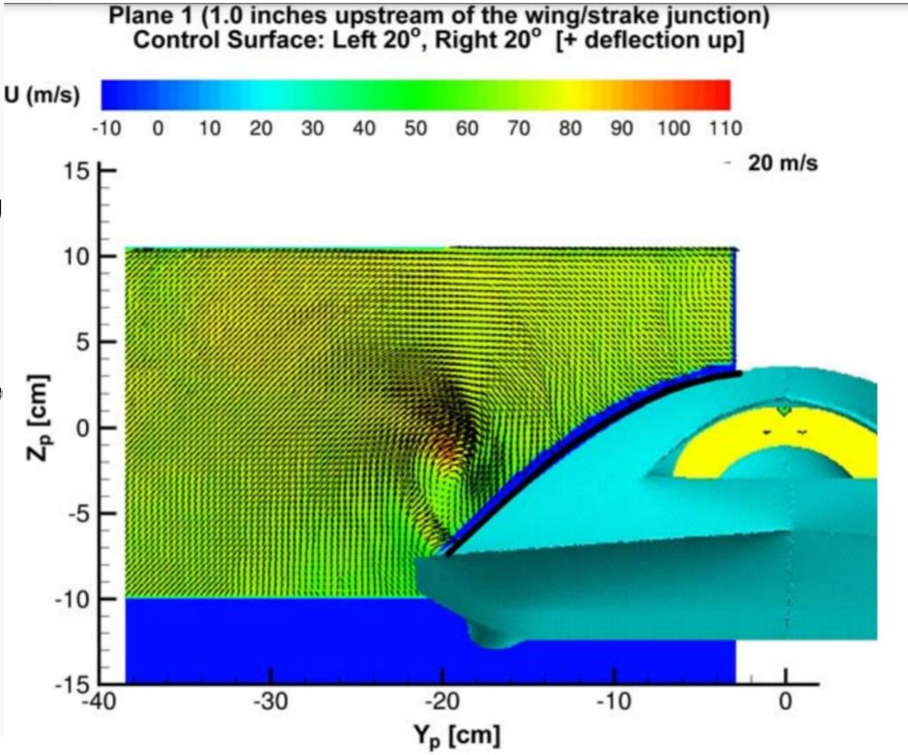




❑ Planar Doppler Velocimetry (PDV) or Doppler Global Velocimetry (DGV)

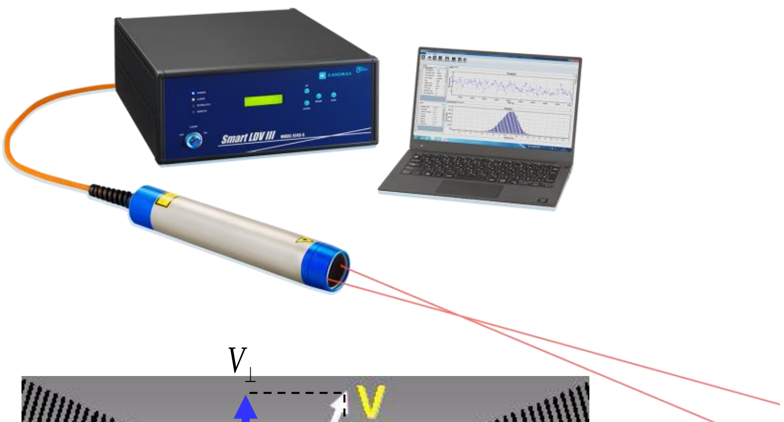
- *Planar Doppler Velocimetry (PDV) or Doppler Global Velocimetry (DGV) can determine instantaneous, three-dimensional velocity vectors of moving particles or solid material in a laser light sheet everywhere in the field of view.*

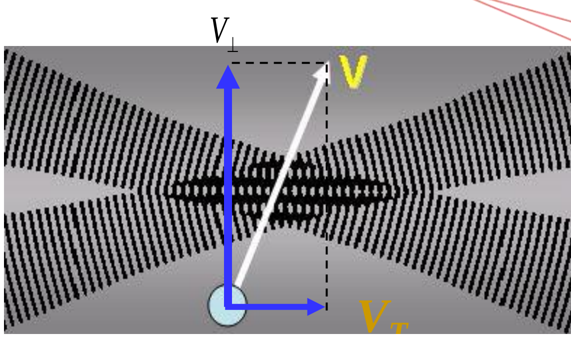


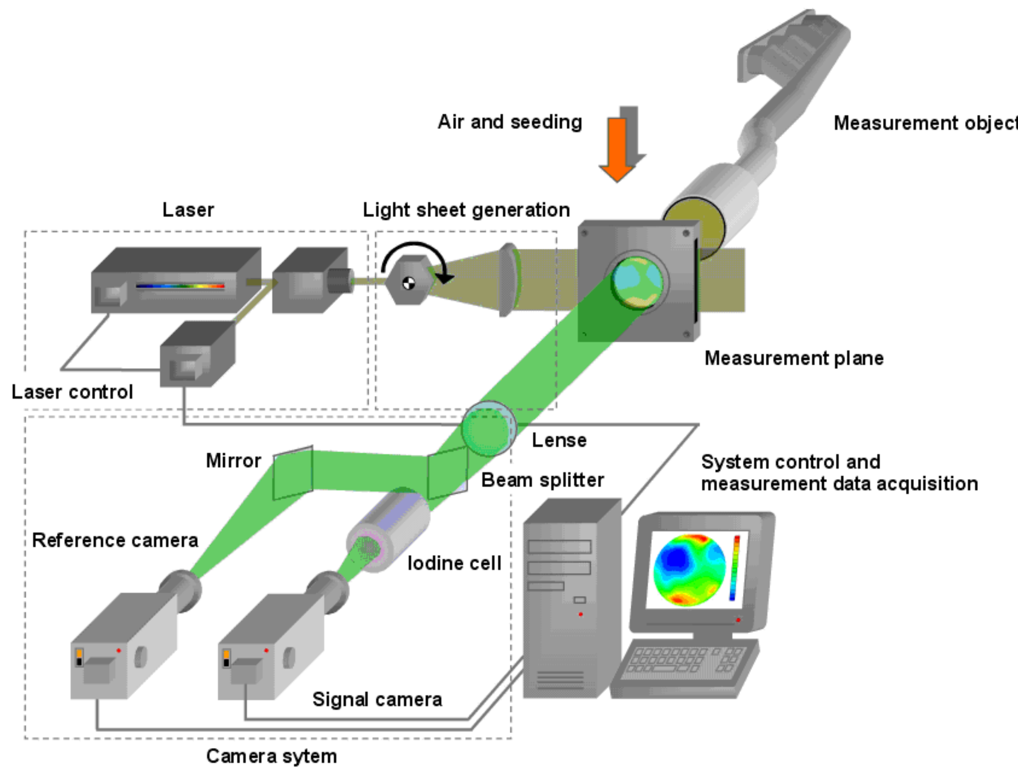


❑ PDV or DGV technique

- *PDV or DGV relies on light scattering (single exposure) by clouds of Particles (high concentration) carried by the flow, rather than the imaging of each individual particle.*
- *It can generate velocity vector field information more quickly than LDV, and over a plane of larger area. Each pixel within the sensor array could yield a potential velocity vector, therefore, a mega pixels imaging camera would potentially output a million velocity vectors at video rate.*



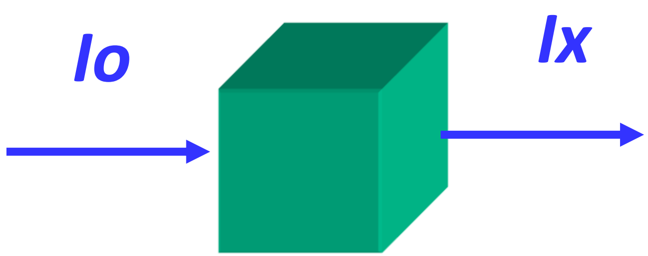




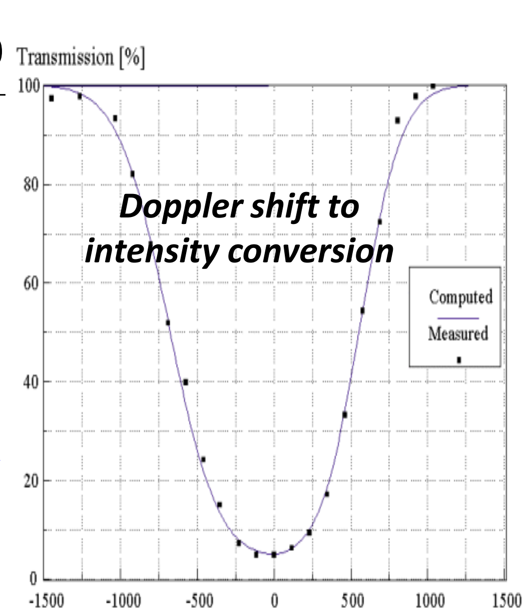
❑ PDV or DGV technique

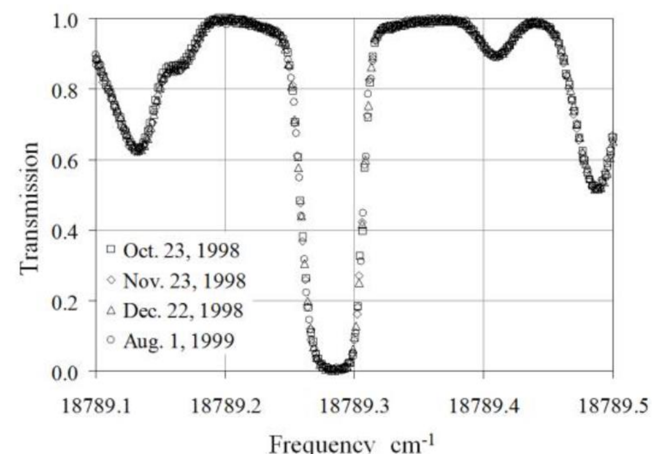
- *In PDV , the velocity information is obtained by means of spectroscopic frequency converter, known as an absorption line filter (ALF), that transforms the Doppler shifted frequency of light scattered by the particles in the flow to image intensity variations in the imaging plane.*
- *Once this transformation is completed, the converted Doppler signal intensity map can then be processed by light intensity detectors (CCD camera) to obtain a velocity map of the flow of interest.*
- *To eliminate the problem of both scattering signal and illumination intensity variations spatially in the measurement window, the Doppler signal intensity map is normalized by a reference intensity map from the same view of the flow.*

$$\Delta f = f_r - f = \frac{V_\phi \cdot 2\sin(\frac{\phi}{2}) f}{f\lambda} = \frac{V_\phi \cdot 2\sin(\frac{\phi}{2})}{\lambda}$$



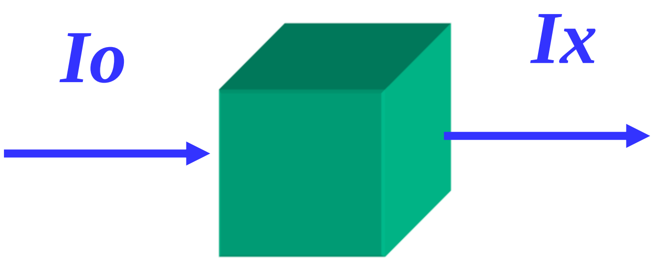
Iodine vapor cell: Absorption line filter



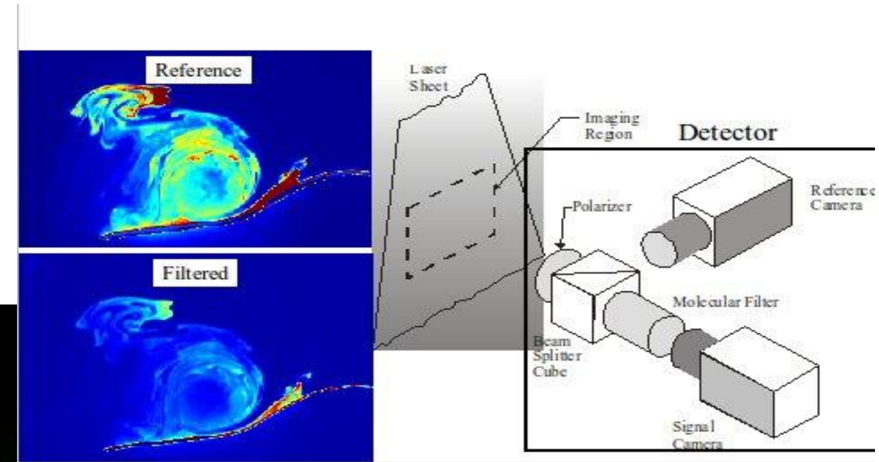


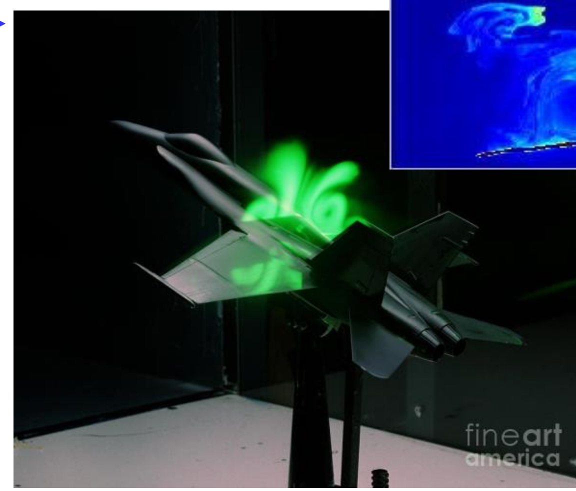
❑ PDV OR DGV TECHNIQUE

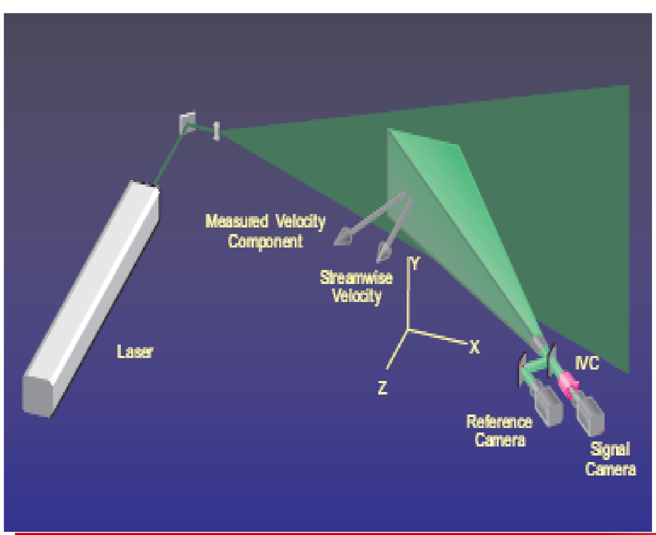
$$\Delta f = f_r - f = \frac{V_\phi \cdot 2\sin(\frac{\phi}{2})\, f}{f\lambda} = \frac{V_\phi \cdot 2\sin(\frac{\phi}{2})}{\lambda}$$

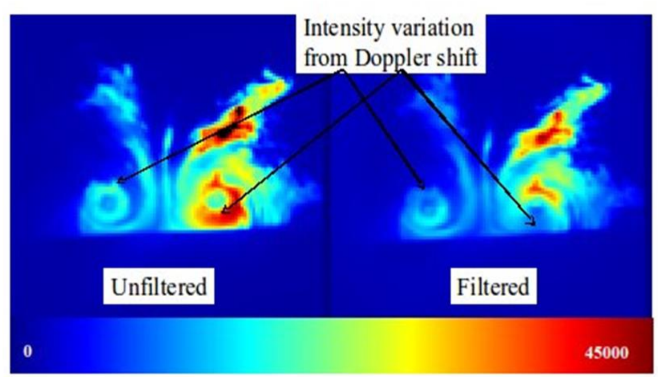


iodine vapor cell: Absorption line filter



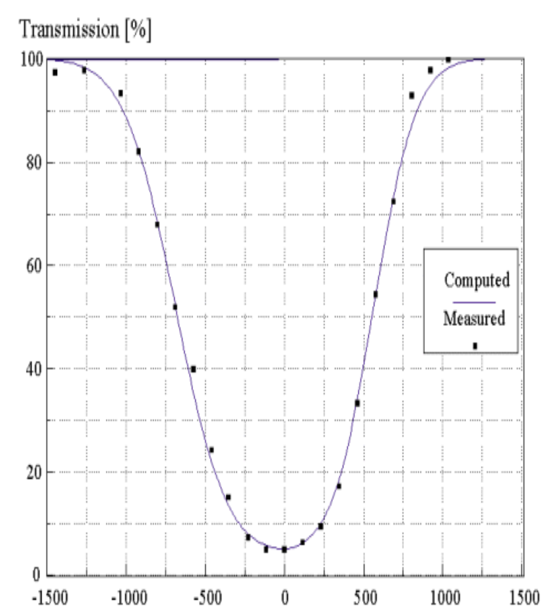






PDV Image before mapping

Doppler shift to intensity conversion



❑ PDV or DGV technique

$$\Delta f = f_r - f = \frac{V_\phi \cdot 2\sin(\frac{\phi}{2}) f}{f\lambda} = \frac{V_\phi \cdot 2\sin(\frac{\phi}{2})}{\lambda}$$

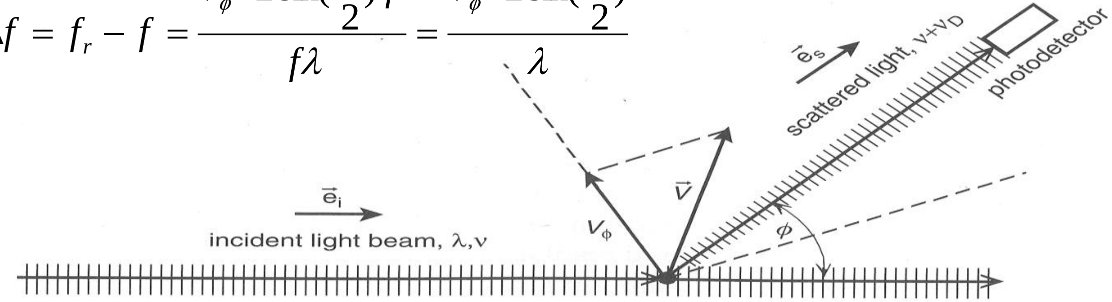
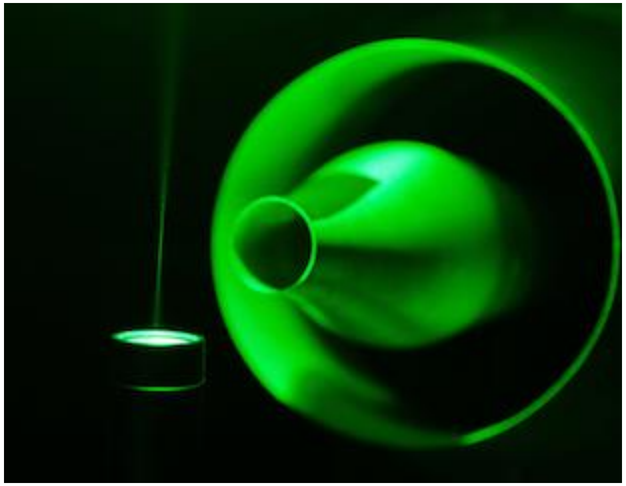
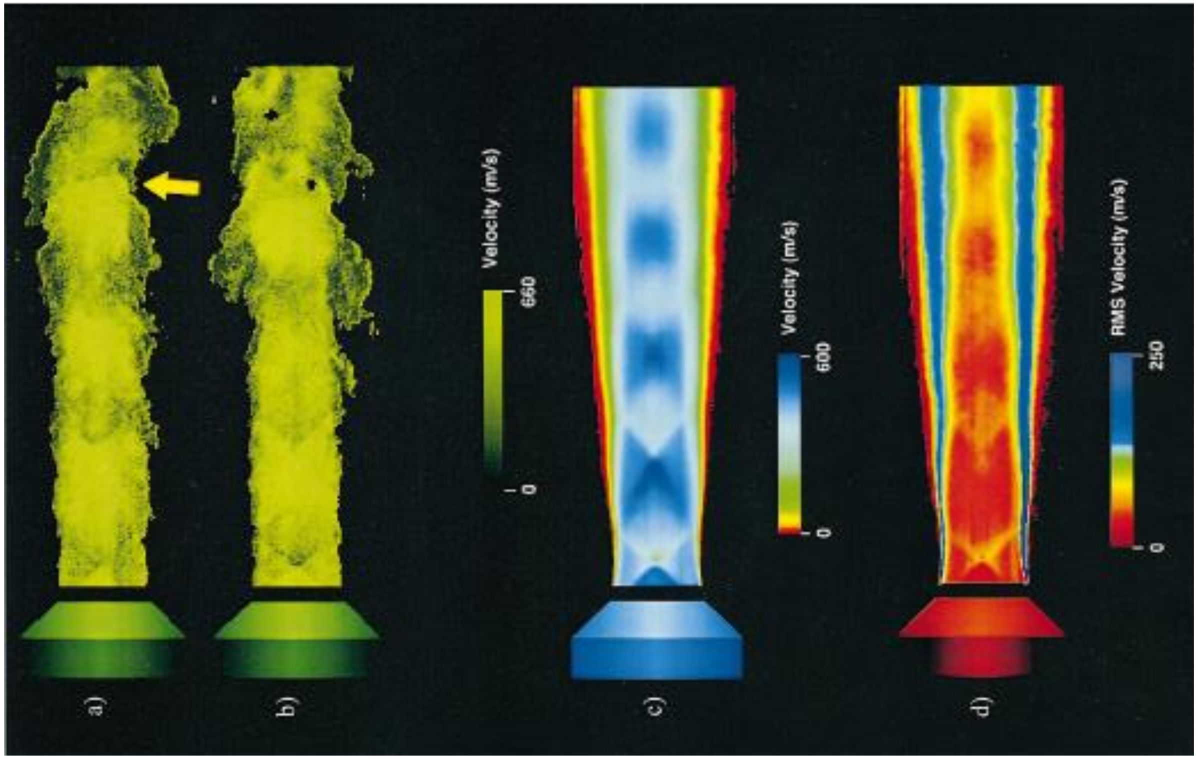
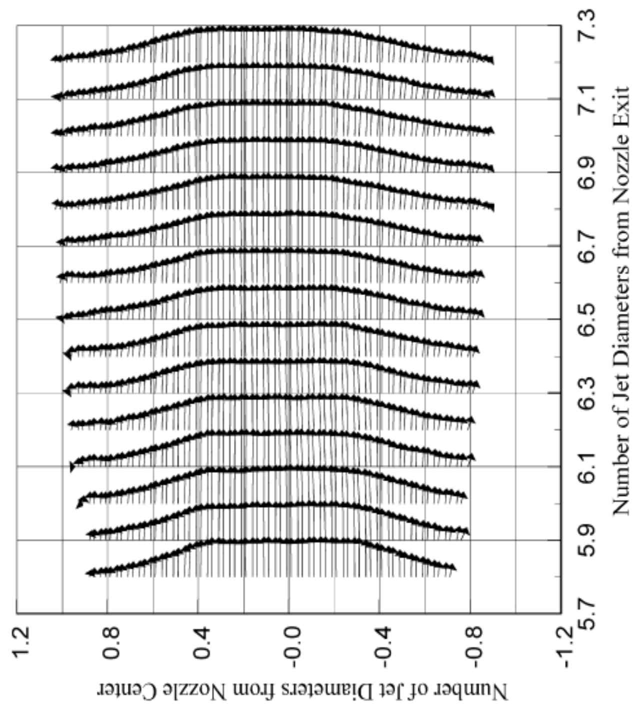


Figure 11.9. Sketch of a laser beam light scattered by a moving particle.



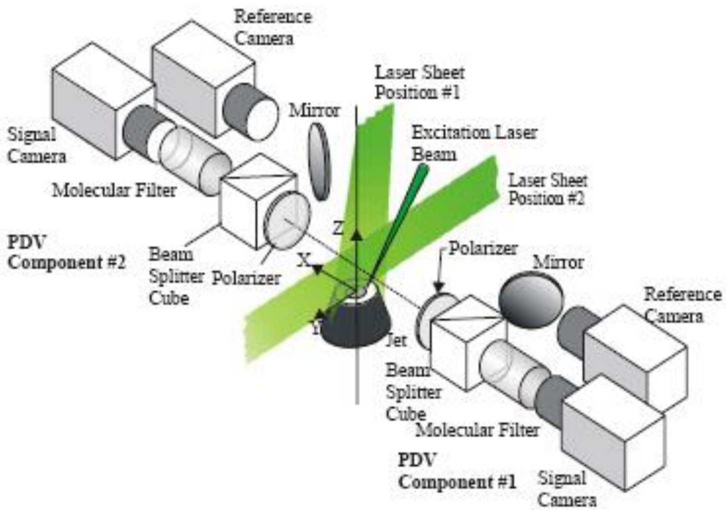




PDV measurements in a supersonic jet

❑ Multi component PDV or DGV technique

$$\Delta f = f_r - f = \frac{V_\phi \cdot 2\sin(\frac{\phi}{2}) f}{f\lambda} = \frac{V_\phi \cdot 2\sin(\frac{\phi}{2})}{\lambda}$$



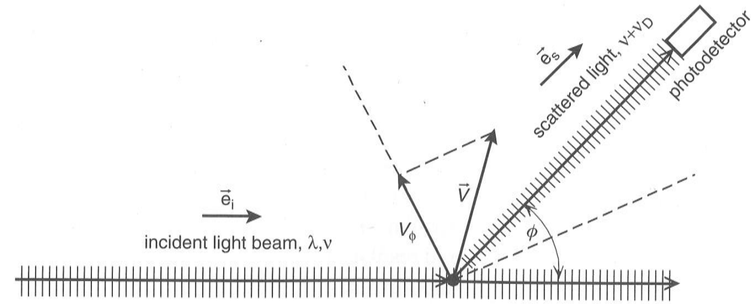
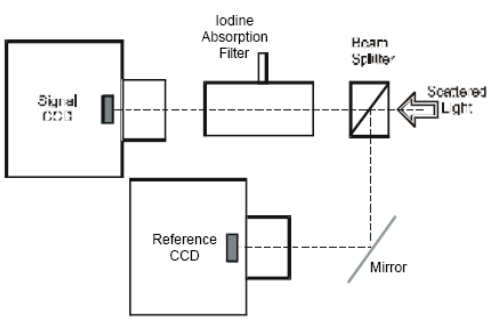
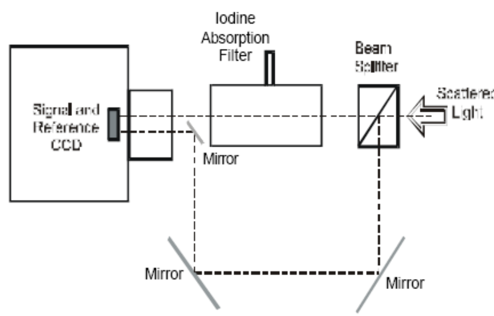


Figure 11.9. Sketch of a laser beam light scattered by a moving particle.



(a)



(b)

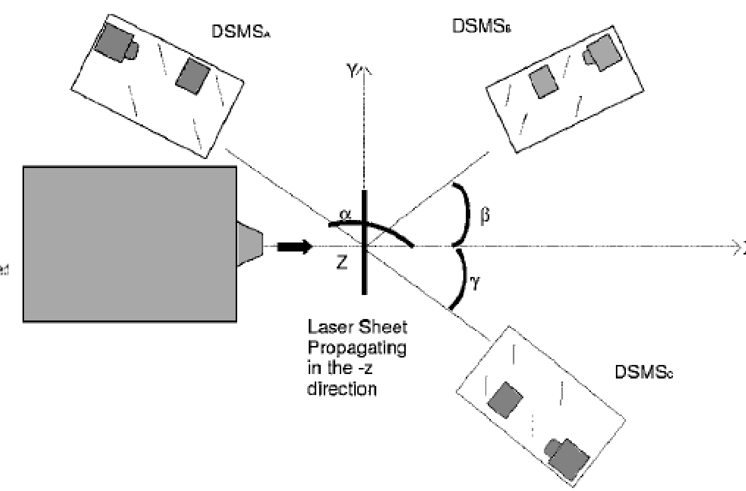


Fig. 2 Plan view of the three-component CS-PDV system.

❑ Advantages and disadvantages of PDV/GDV technique

- ***Advantages:***
  - ***PDV is well suited for high-speed flow measurements where concerns about particle seeding make PIV impractical.***
  - ***Although PDV requires particles to scatter light, individual particles do not need to be imaged thus allowing the use of much smaller seed particles and making the measurements less sensitive to particle seed density.***
  - ***In addition, PDV has an inherently higher resolution than PIV as smaller image subregions can be used to determine the velocity.***

- ***Disadvantages***
  - ***The main weakness of PDV is the complex optical set up required to get accurate measurements (position registration, etc..).***
  - ***For each component of velocity, two images (signal and reference) are required, which typically necessitates two cameras. To obtain all three components of velocity, therefore, requires the simultaneous use of up to six cameras.***
  - ***In addition, the laser used for the measurements must be narrow linewidth, which is typically performed by injection seeding of the laser cavity.***
  - ***PDV systems, although used in many laboratories, are not yet commercially available and can be quite expensive (equipment, data processing, experience, labor, etc.) if built from scratch.***