Lecture 14: Particle Image Velocimetry (PIV) - Part 01

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Particle-based Flow Diagnostic Techniques

- *Seeded the flow with small particles (~ μm in size)*

- ***Assumption**: the particle tracers move with the same velocity as local flow velocity!*

Flow velocity V_f = **Particle velocity V_p**

Measurement of particle velocity

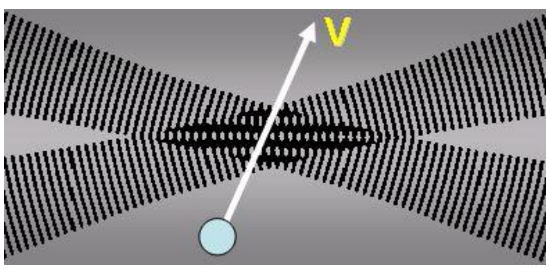
- *Smoke visualization*

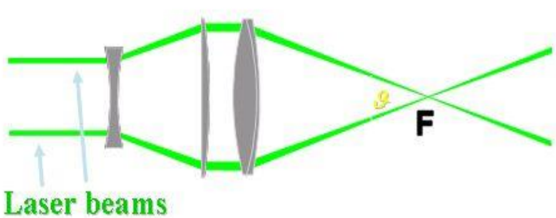
❑ Frequency-shift based methods

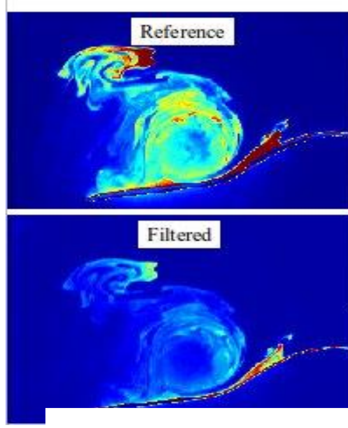
• Frequency-shift methods:

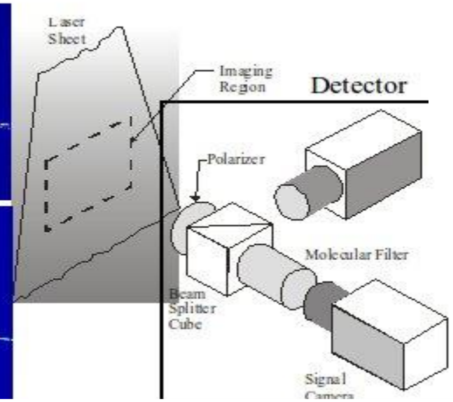
- *Based on the Doppler phenomenon, namely the shift of the frequency of waves scattered by moving particles.*
- *Laser Doppler Velocimetry(LDV) or Laser Doppler Anemometry (LDV)*
- *Planar Doppler Velocimetry (PDV) or Planar Doppler Anemometry (PDA)*

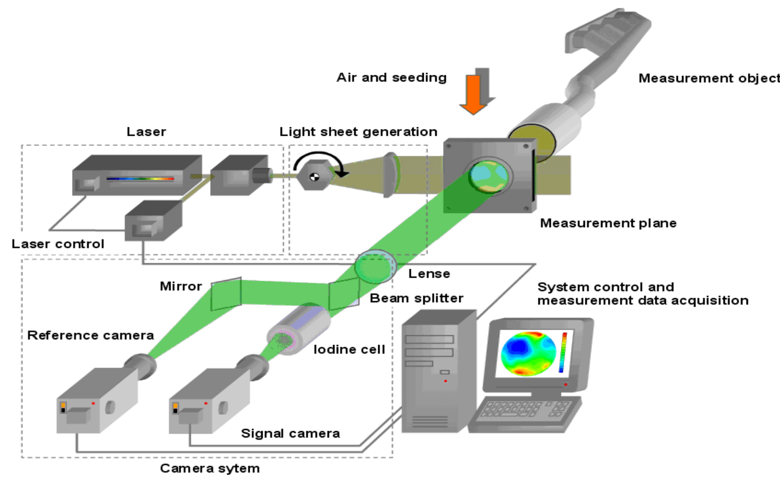
$$v_{\perp} = \frac{\lambda}{2\sin\frac{\vartheta}{2}} f$$



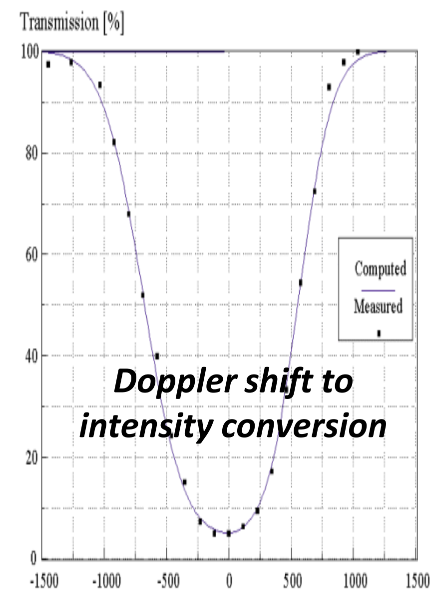






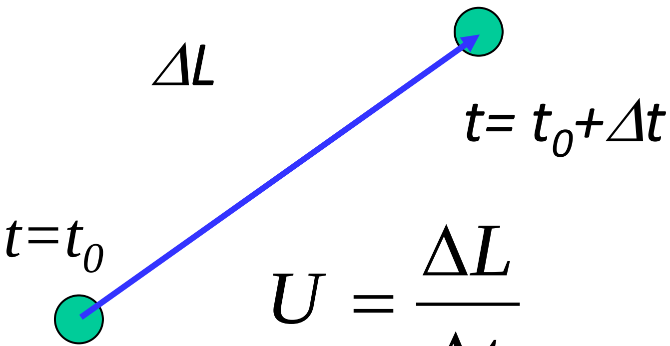


- ***Doppler effects***

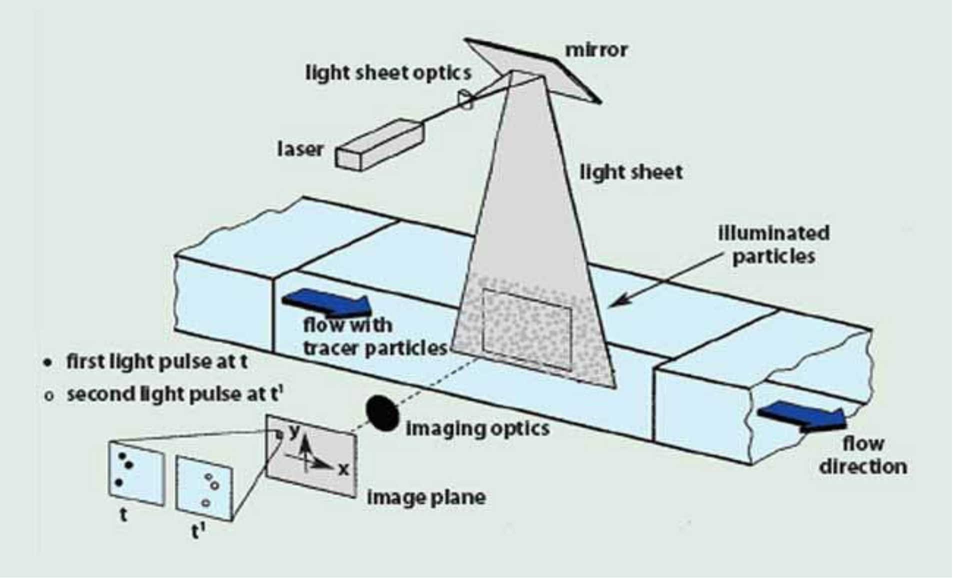


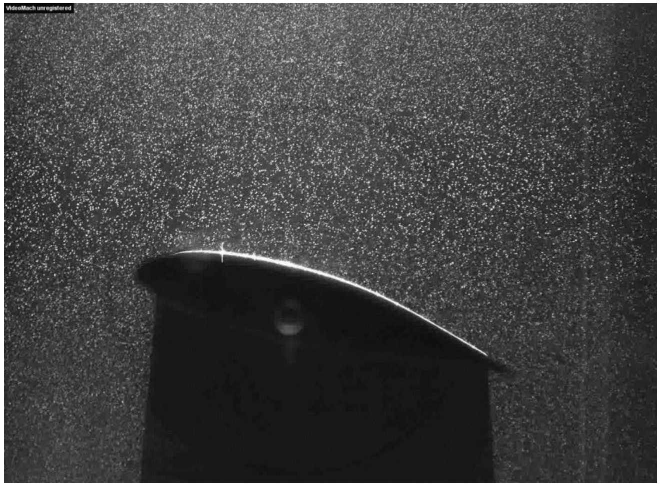
❑ Particle Image Velocimetry (PIV) technique

- ***Time-of-flight method:*** *to measure the displacements of the tracer particles seeded in the flow in a fixed time interval.*

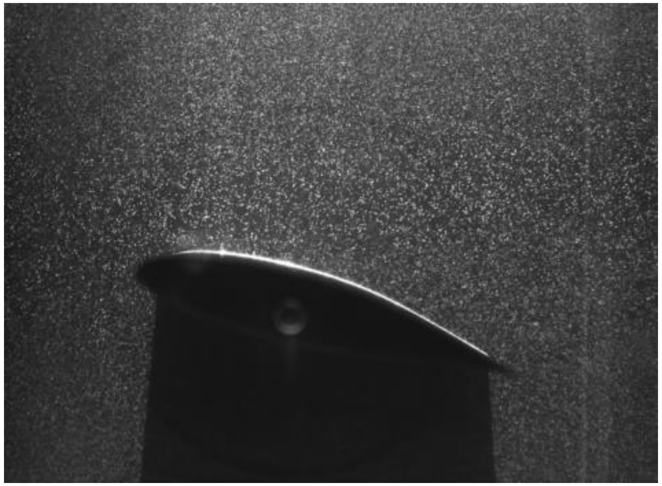


$$U = \frac{\Delta L}{\Delta t}$$

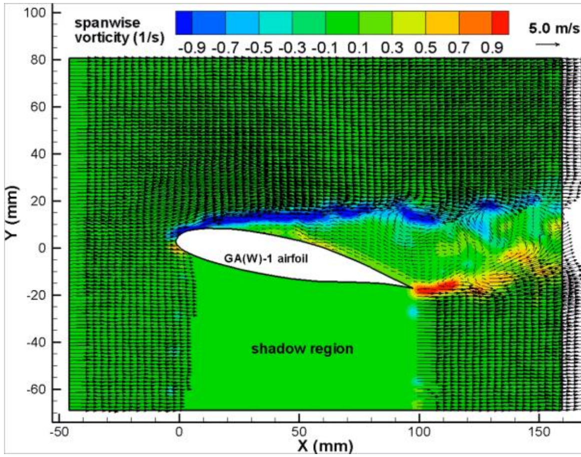




a. T=t0



b. T=t0+10μs



Corresponding Velocity field

❑ PIV System Setup

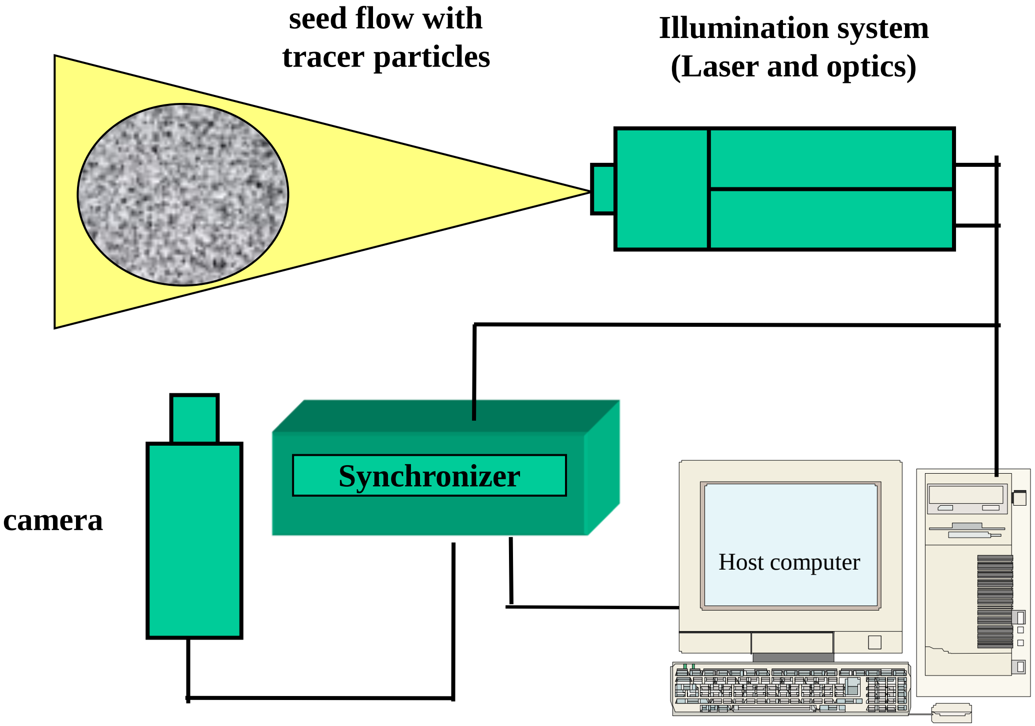
Particle tracers: *to track the fluid movement.*

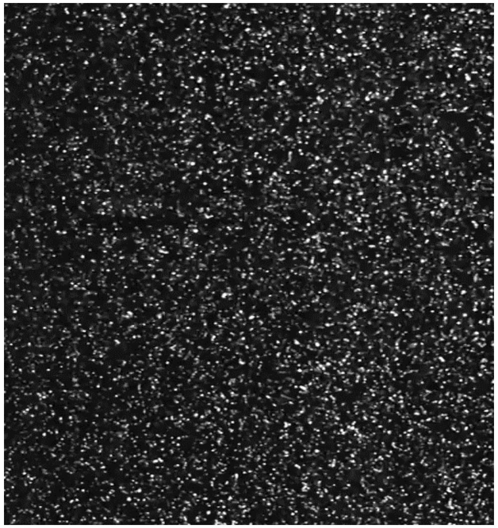
Illumination system: *to illuminate the flow field in the interest region.*

Camera: *to capture the images of the particle tracers.*

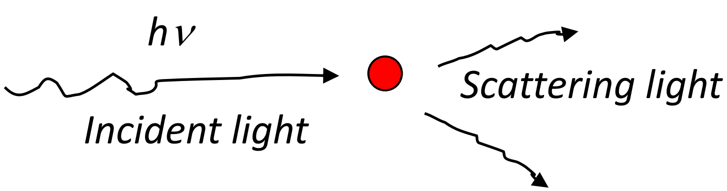
Synchronizer: *the control the timing of the laser illumination and camera acquisition.*

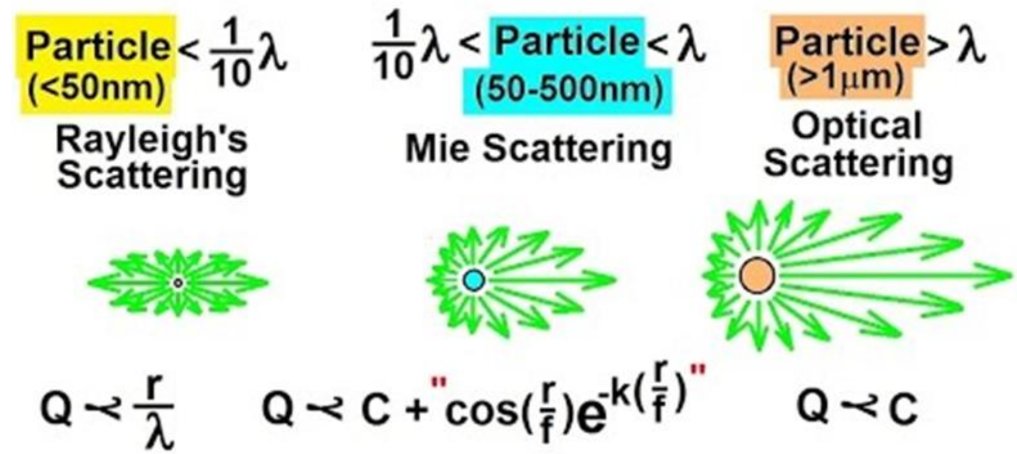
Host computer: *to store the particle images and conduct image processing.*



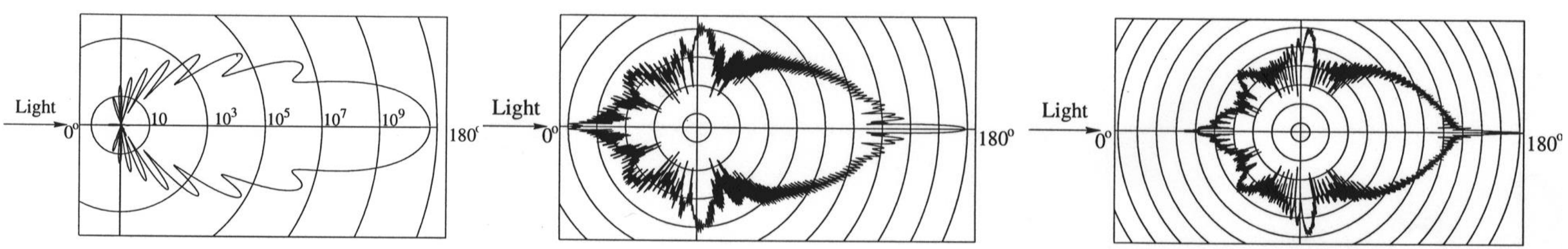


❑ Tracer Particles for PIV





- *Tracer particles should be neutrally buoyant and small enough to follow the flow perfectly.*
- *Tracer particles should be big enough to scatter the illumination lights efficiently .*
- *The scattering efficiency of trace particles also strongly depends on the ratio of the refractive index of the particles to that of the fluid.*
  For example: the refractive index of water is considerably larger than that of air. The scattering of particles in air is at least one order of magnitude more efficient than the same particles size in water.



a). d=1μm *b). d=10μm* *c). d=30μm*

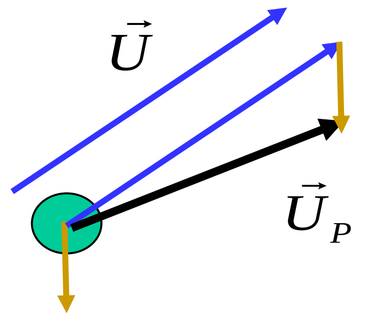
❑ Tracer Particles for PIV

- *A primary source of measurement error is the influence of gravitational forces when the density of the tracer particles is different to the density of work fluid.*
- *The velocity lag of a particle in a continuously acceleration fluid will be:*

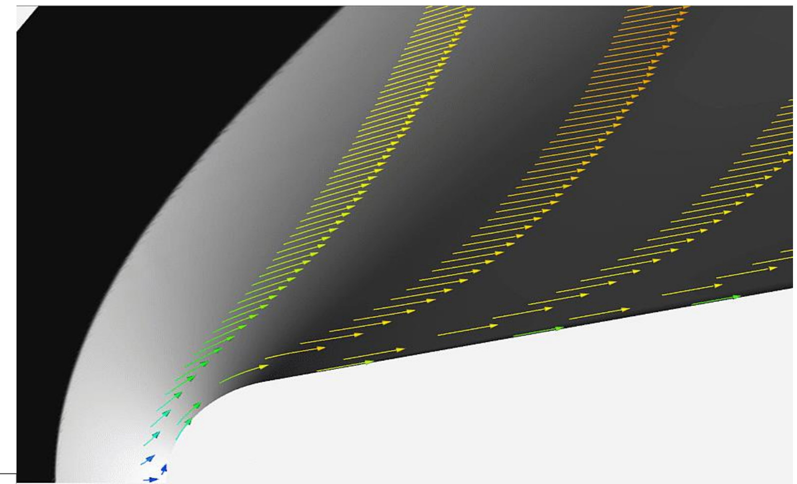
$$\vec{U}_s = \vec{U}_P - \vec{U} = d_p^{\,2} \frac{(\rho_p - \rho)}{18\mu} g$$

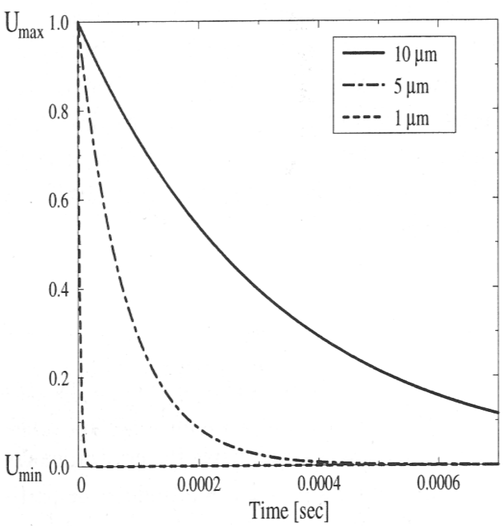
$$\vec{U}_p(t) = \vec{U}\left(1 - \exp\left(-\frac{t}{\tau_s}\right)\right);$$

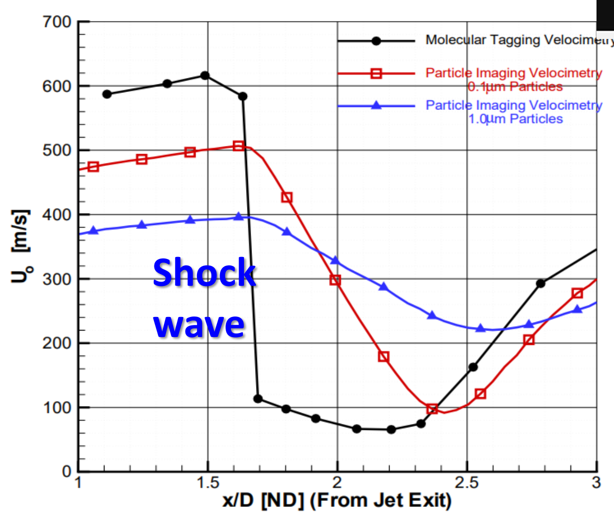
$$\tau_s = d_p^{\,2} \frac{\rho_p}{18\mu}$$

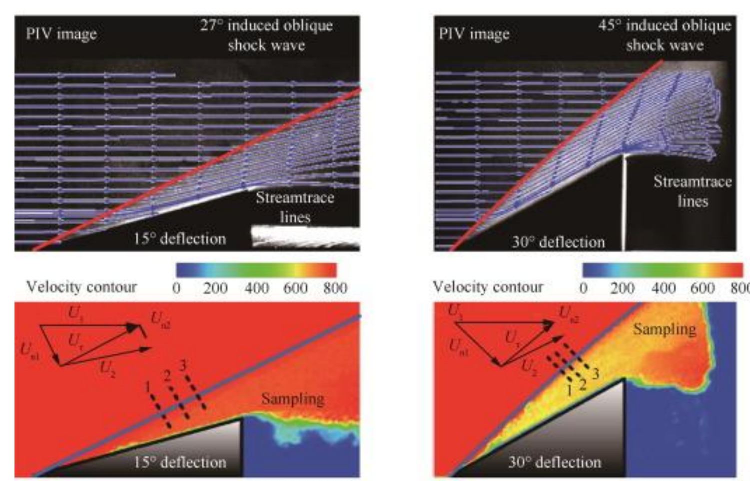


$$U_g = d_p^{\,2} \frac{(\rho_p - \rho)}{18\mu} g$$









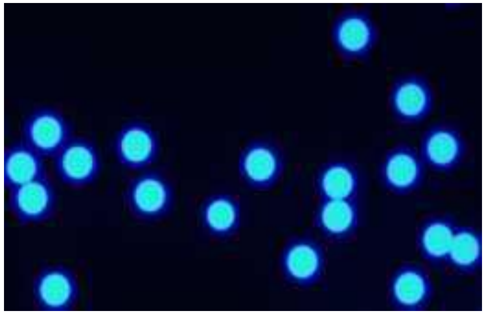
(a) A wedge with deflection angle 15°

(b) A wedge with deflection angle 30°

❑ Tracer Particles for PIV

- *Tracers for PIV measurements in liquids (water):*
  - *Polymer particles (d=10~100 μm, density = 1.03 ~ 1.05 kg/cm^3)*
  - *Silver-covered hollow glass beams (d =1 ~10 μm, density = 1.03 ~ 1.05 kg/cm3)*
  - *Fluorescent particle for micro flow (d=200~1000 nm, density = 1.03 ~ 1.05 kg/cm3).*
  - *Quantum dots (d= 2 ~ 10 nm)*

roduct
Polyamide particles, 55 µm, 1.2g/cm³
Polyamide particles, 100 µm, 1.1 g/cm³
Polyamide particles HQ, 20 µm, 1.03g/cm³
Polyamide particles HQ, 60 µm, 1.03g/cm³



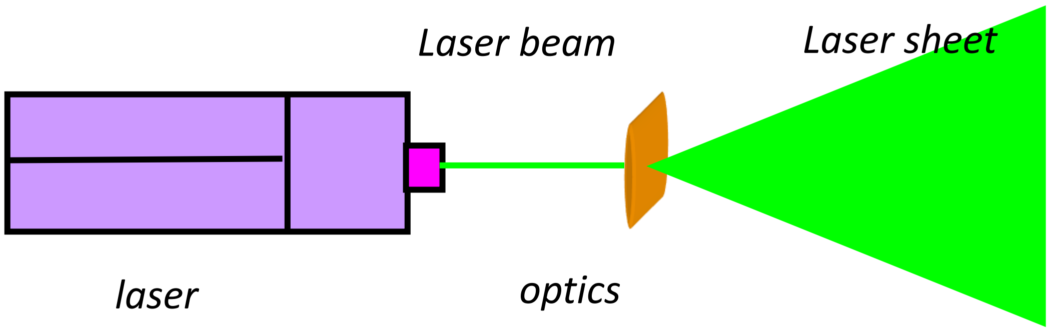
- *Fluorescent particle*

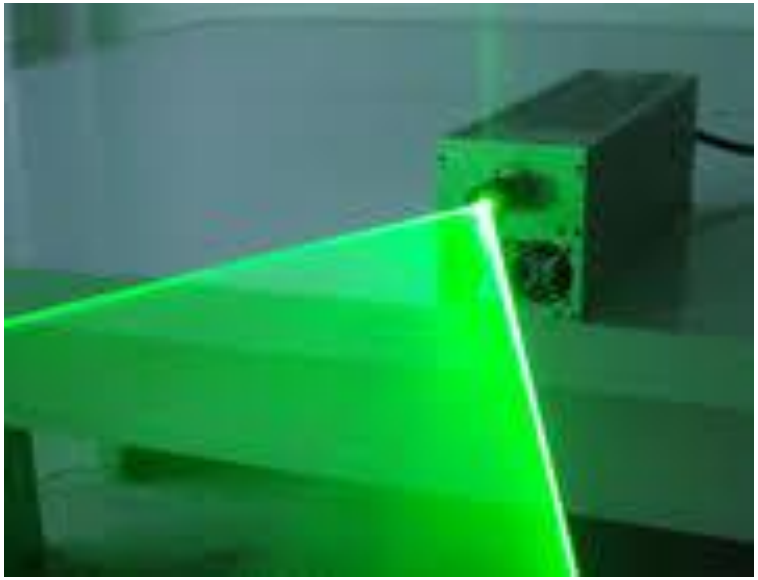
- *Tracers for PIV measurements in gaseous flows:*
  - *Smoke …*
  - *Droplets, mist, vapor…*
  - *Condensations ….*
  - *Hollow silica particles (0.5 ~ 2 µm in diameter and 0.2 g/cm3 in density for PIV measurements in combustion applications.*
  - *Nanoparticles of combustion products*

- *~ 1 µm droplets in airflow*

❑ ILLUMINATION SYSTEM

- *The illumination system of PIV is always composed of light source and optics.*
- ***Lasers**: such as Argon-ion laser and Nd:YAG Laser, are widely used as light source in PIV systems due to their ability to **emit monochromatic light** with **high energy density** which can easily be bundled into thin light sheet for illuminating and recording the tracer particles without chromatic aberrations.*
- ***Optics**: always consisted by a set of cylindrical lenses and mirrors to shape the light source beam into a planar sheet to illuminate the flow field.*





❑ Double-pulsed Nd:YAG Laser for PIV

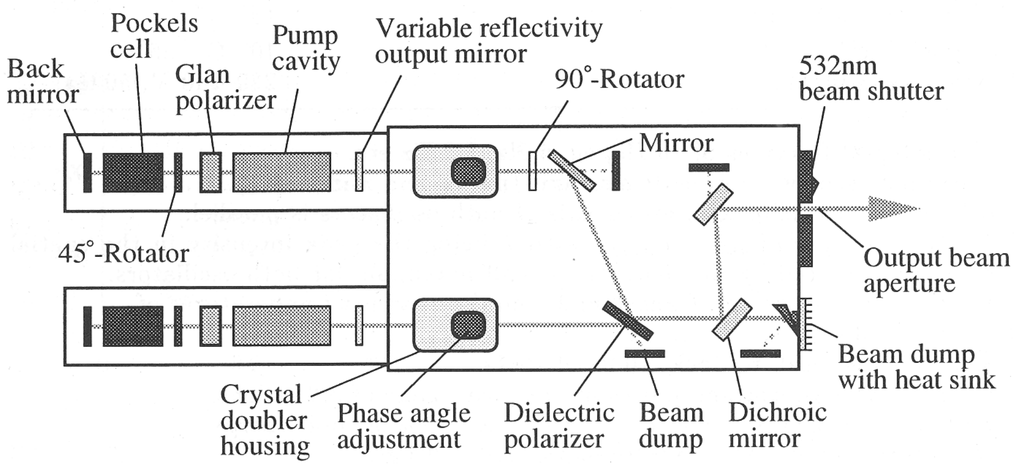
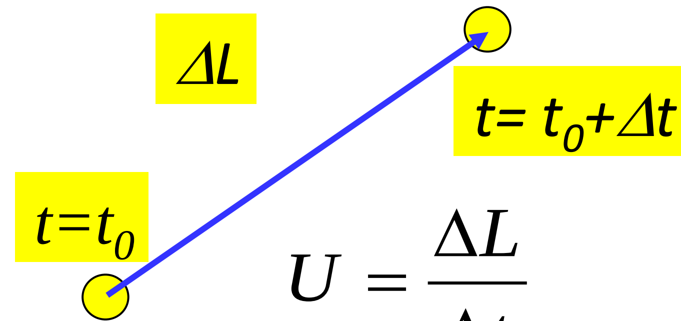
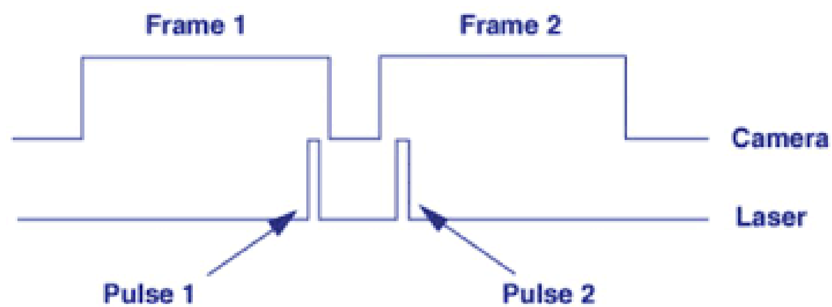


Fig. 2.17. Double oscillator laser system with critical resonators



$$U = \frac{\Delta L}{\Delta t}$$



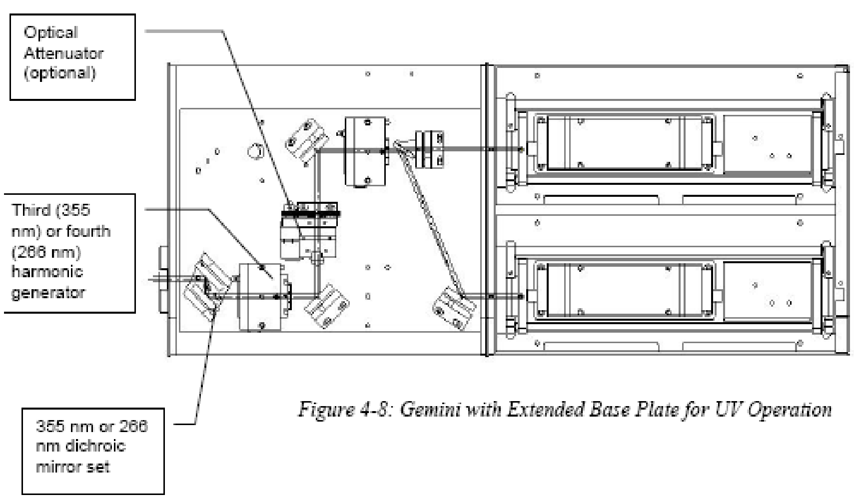
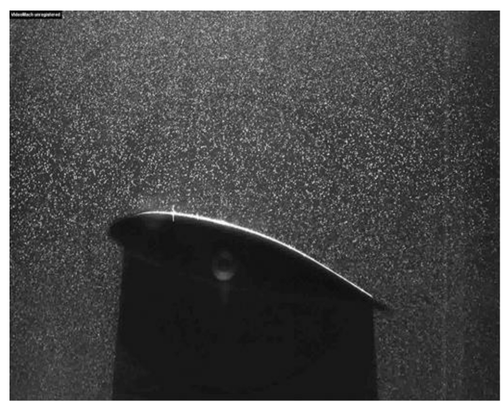
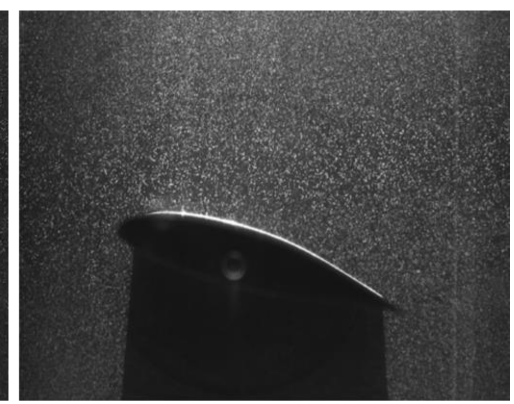


Figure 4-8: Gemini with Extended Base Plate for UV Operation

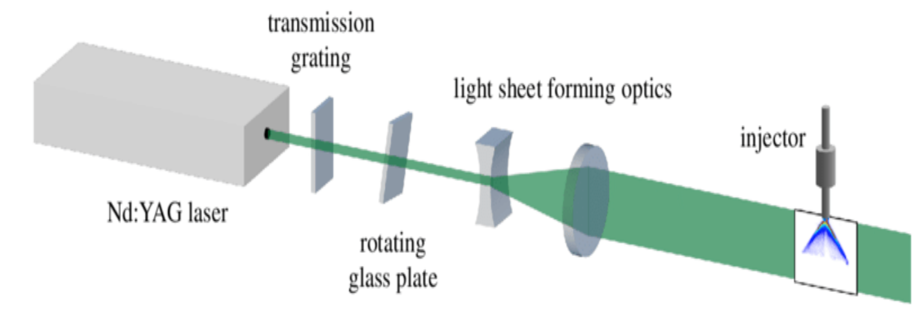


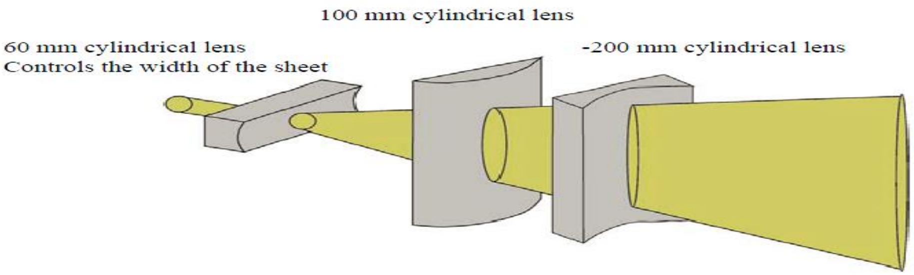
a. T=t0

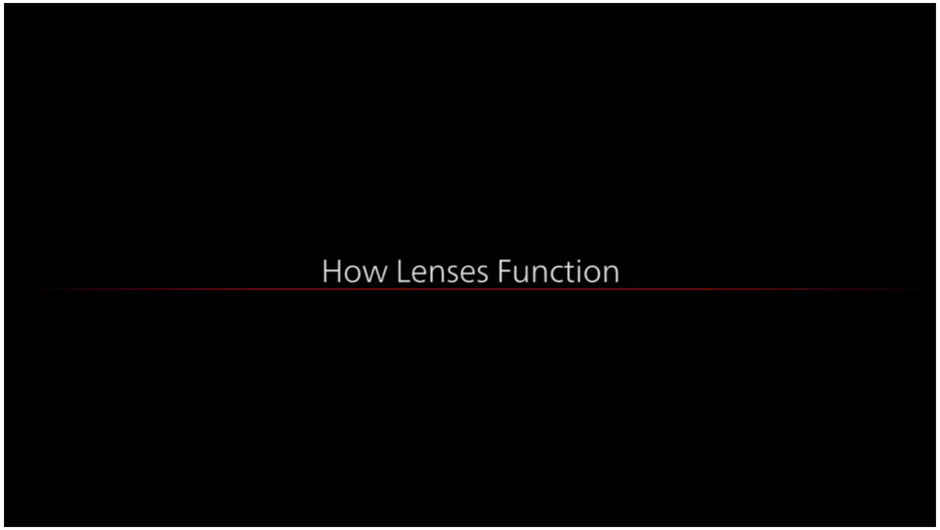


b. T=t0+10μs

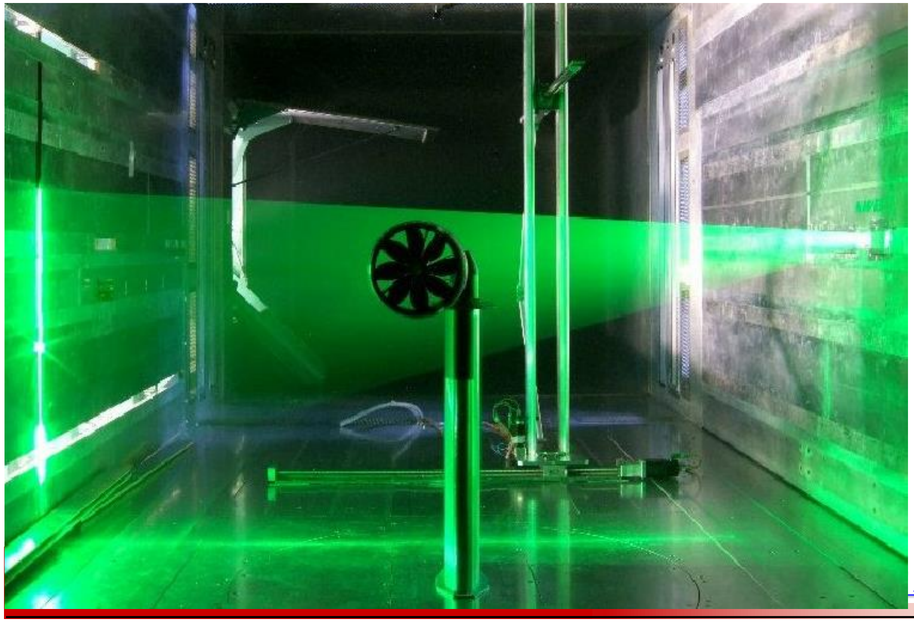
❑ Optics/Lenses to shape Laser Beam to Sheet







- https://www.youtube.com/watch?v=EL9J3Km6wxI



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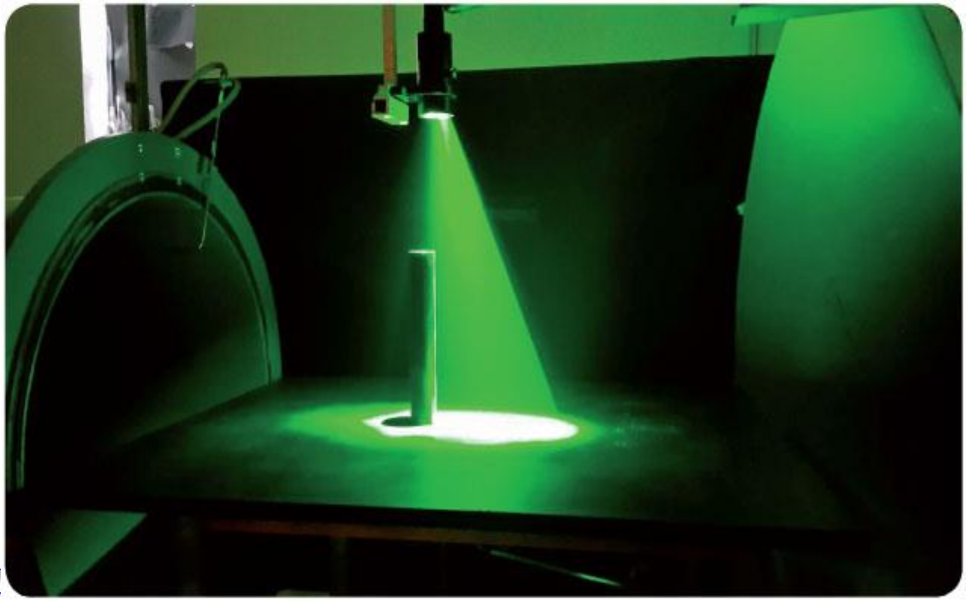
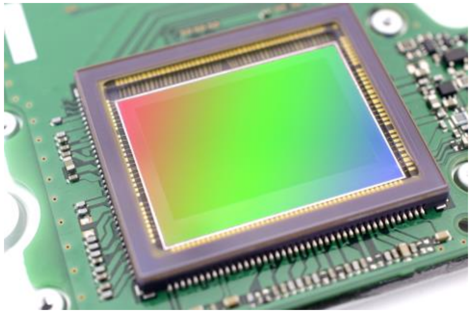


❑ Image Acquisition System: Cameras

- *The widely used cameras for PIV:*
  - *Photographic film-based cameras or digital cameras.*

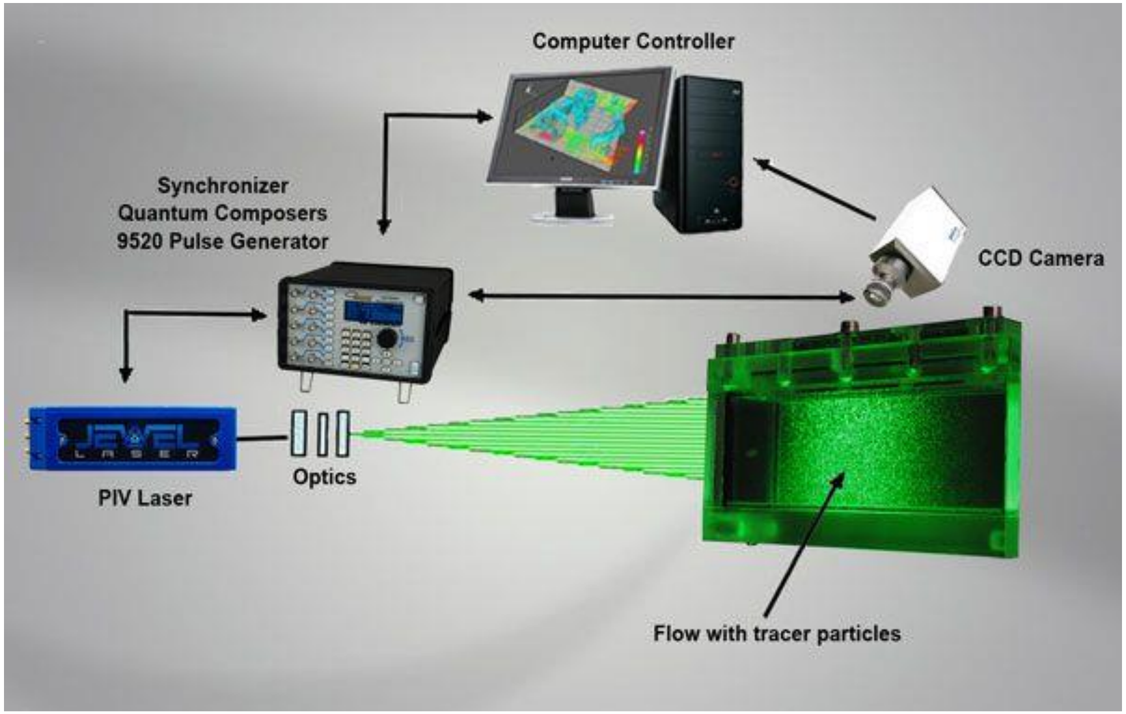
- *Advantages of digital cameras:*
  - *It is fully digitized*
  - *Various digital techniques can be implemented for PIV image processing.*
  - *Conventional auto- or cross-correlation techniques combined with special framing techniques can be used to measure higher velocities.*

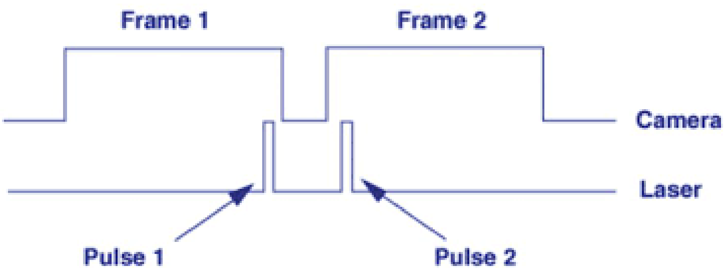
- *Disadvantages of digital cameras:*
  - *Low temporal resolution (defined by the video framing rate):*
  - *Low spatial resolution:*

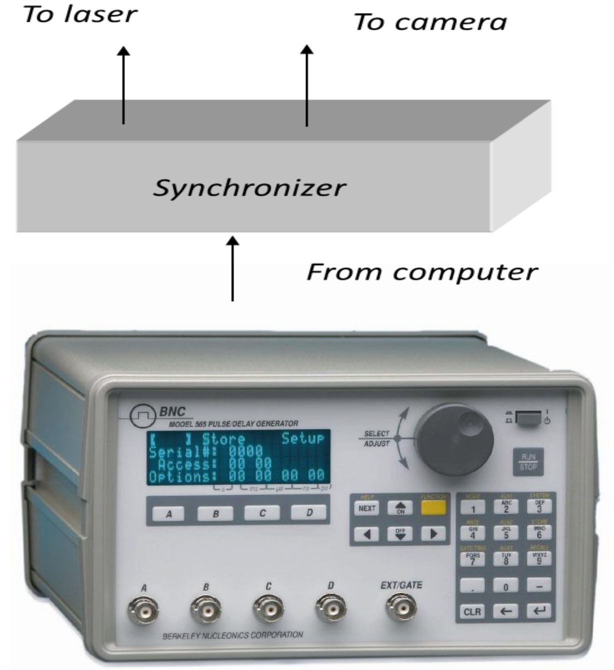


❑ Synchronizer

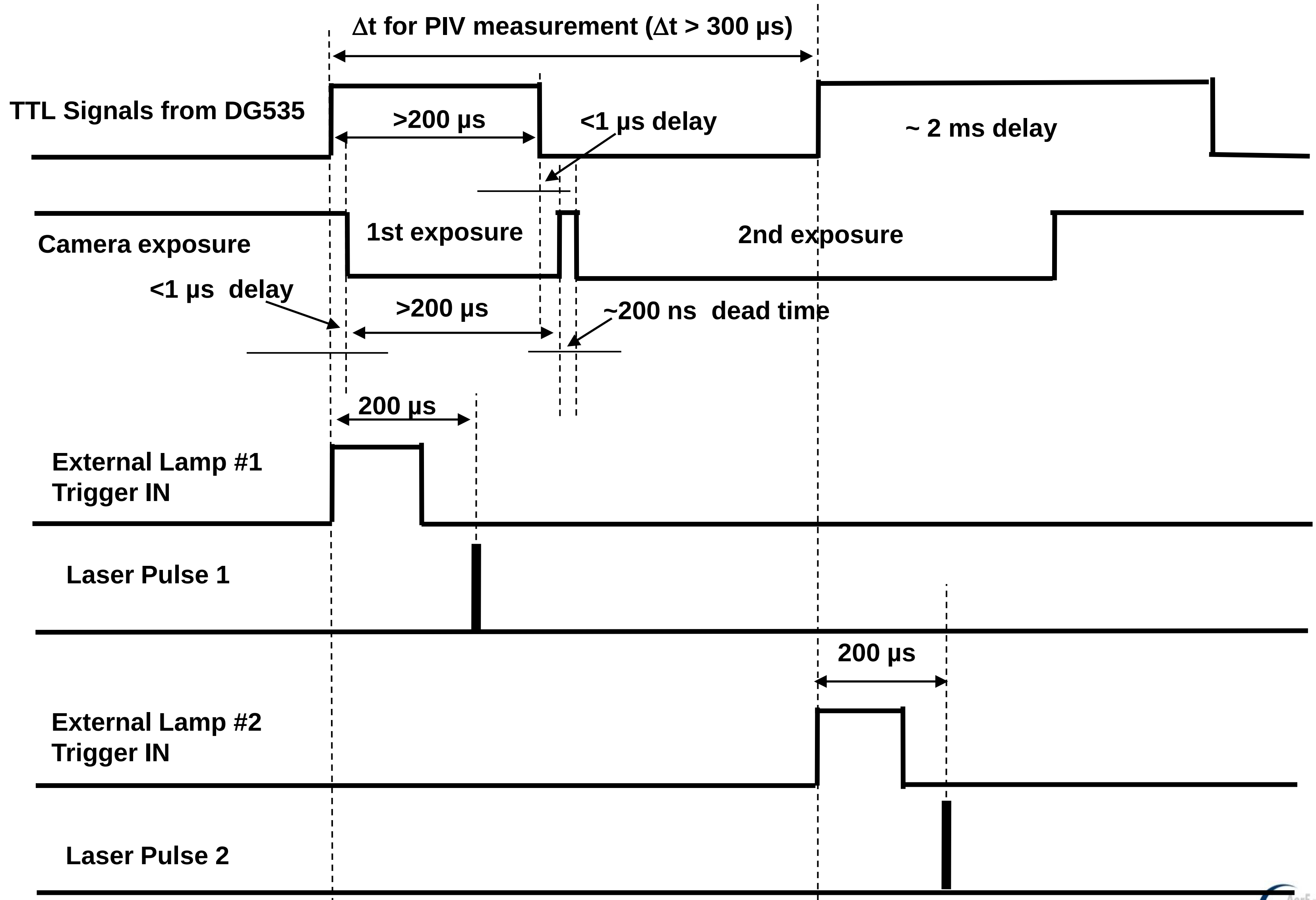
- *Function of Synchronizer:*
  - *To control the timing of the laser illumination and camera acquisition*







❑ Time Chart of the PIV Measurements (Δt > 300 μs)



❑ HOST COMPUTER

- *To send timing control parameter to synchronizer.*
- *To store the particle images and conduct image processing.*