



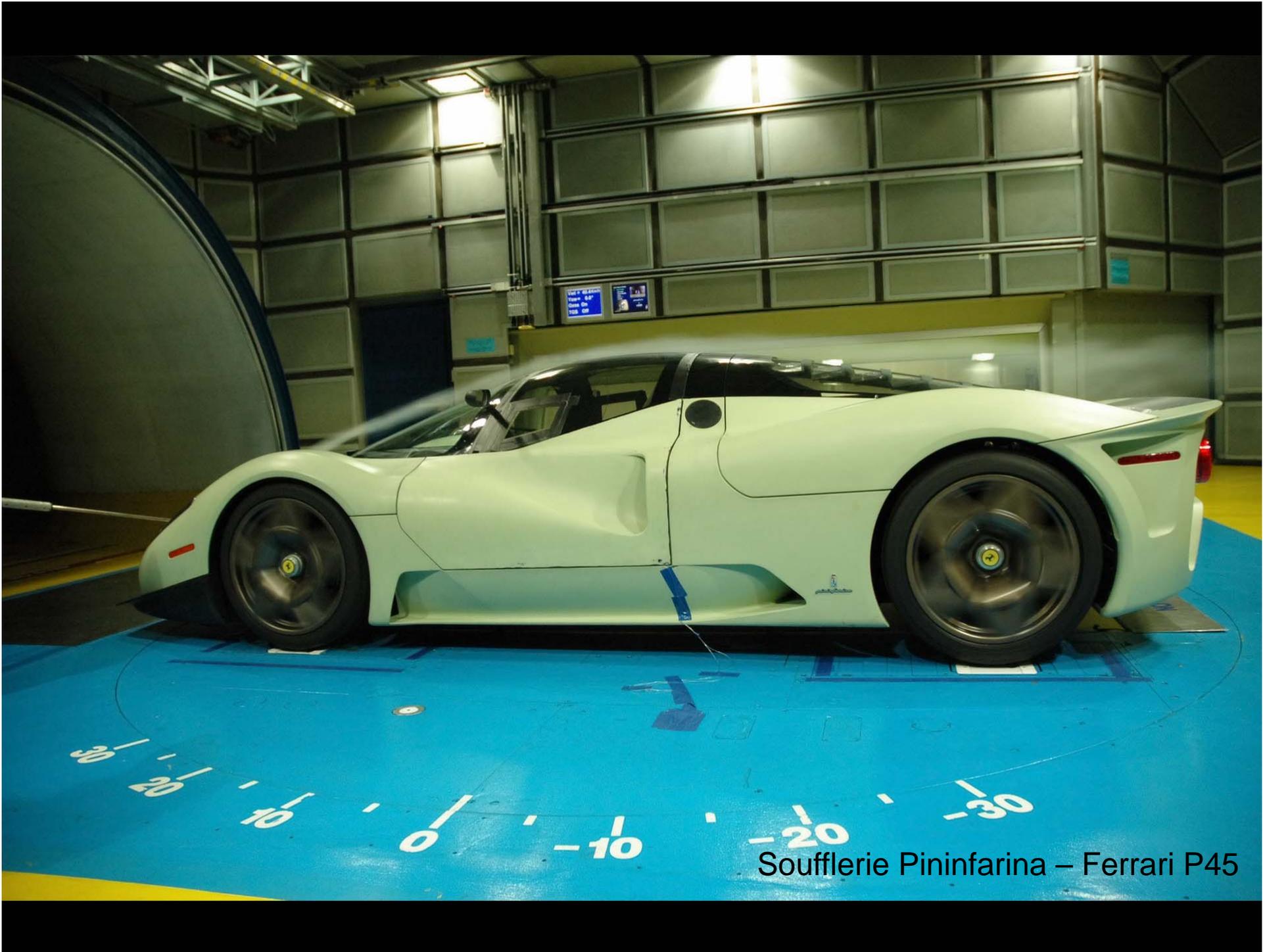
Master 1 de Physique Appliquée et Mécanique

2014-2015

Méthodes Expérimentales en Mécanique des Fluides

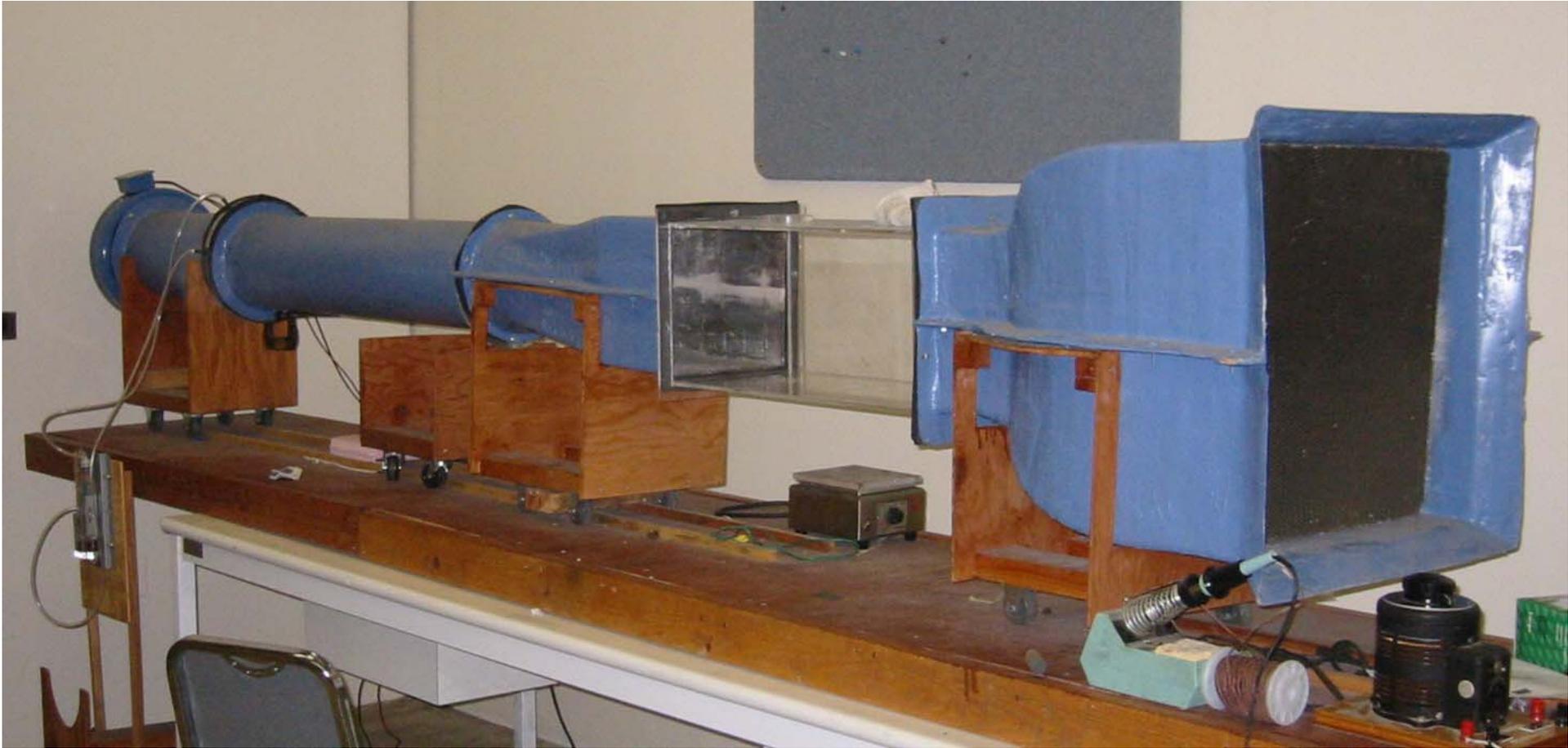
Frédéric MOISY

**Université Paris-Sud
Laboratoire FAST
Bâtiment 502 – 91405 Orsay**

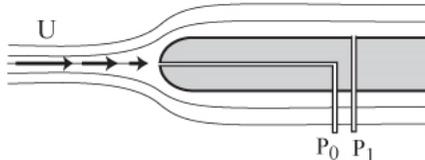
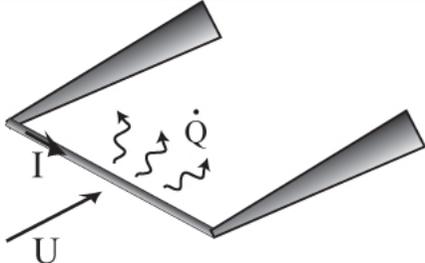
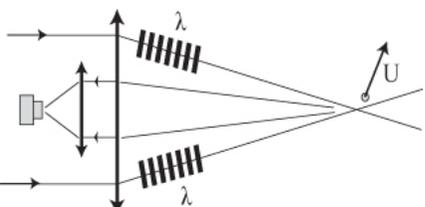
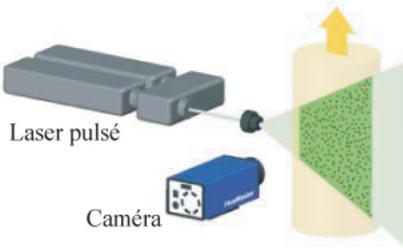


Soufflerie Pininfarina – Ferrari P45

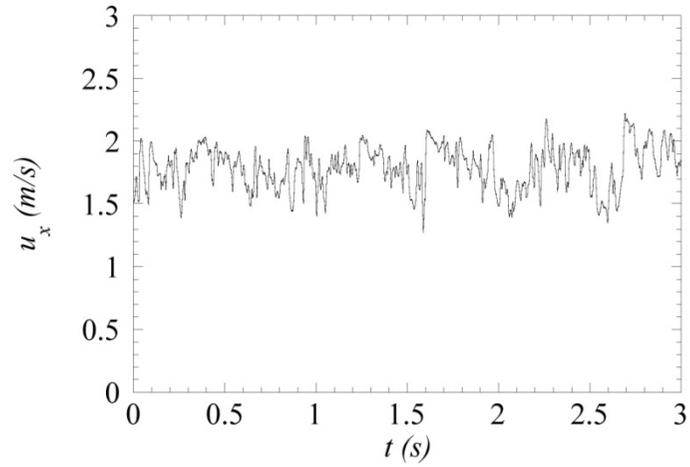




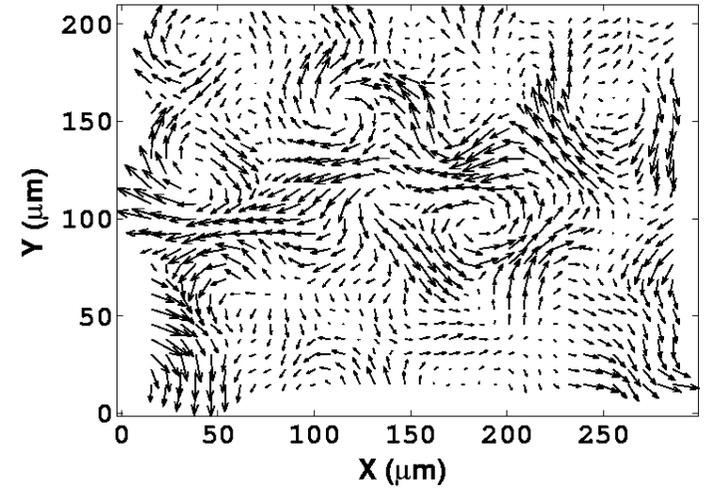
Les mesures de vitesse

	TUBE DE PITOT	ANEMOMETRE A FIL CHAUD (HOT WIRE ANEMOMETRY)	ANEMOMETRE LASER DOPPLER (LASER DOPPLER VELOCIMETRY, LDV)	VELOCIMETRIE PAR IMAGES DE PARTICULES (PIV)
Schéma				
Principe	Mesure de 2 pressions (statique et dynamique) ? Bernouilli $U = \sqrt{2(P_d - P_s) / \rho}$	Mesure de la puissance RI^2 dissipée par un fil chauffé.	Mesure (par interférométrie) du décalage Doppler sur particule diffusante.	Mesure du déplacement de particules entre deux images (méthode de corrélations)
Avantages	Mise en œuvre très simple, bon marché (~ 1 k€) Idéal pour profils de vitesse moyenne	Excellente résolution spatiale et temporelle (idéal pour mesures de fluctuations turbulentes). Mise en œuvre assez simple, coût modéré (~ 10 - 20 k€).	Non intrusif. Calibration linéaire. Très bonne résolution spatiale et temporelle (idéal pour mesures de fluctuations turbulentes). Possibilité mesure plusieurs composantes.	Non intrusif. Champ 2D instantané.
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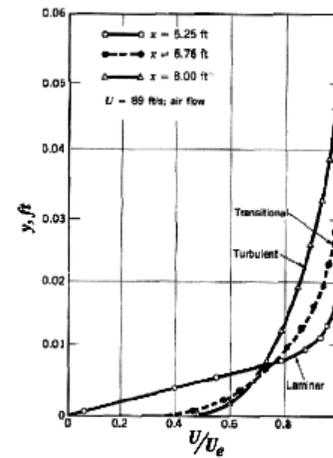
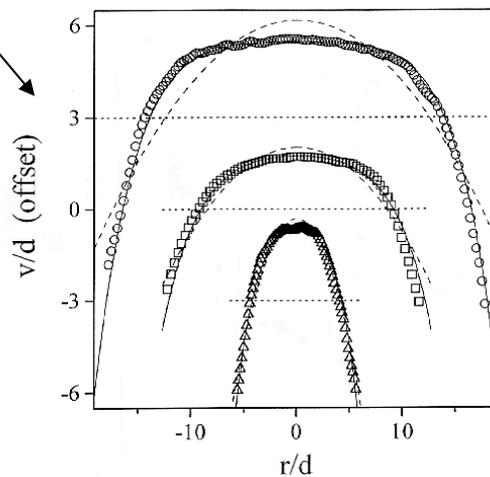
Instantané en 1 point (HWA, LDV)



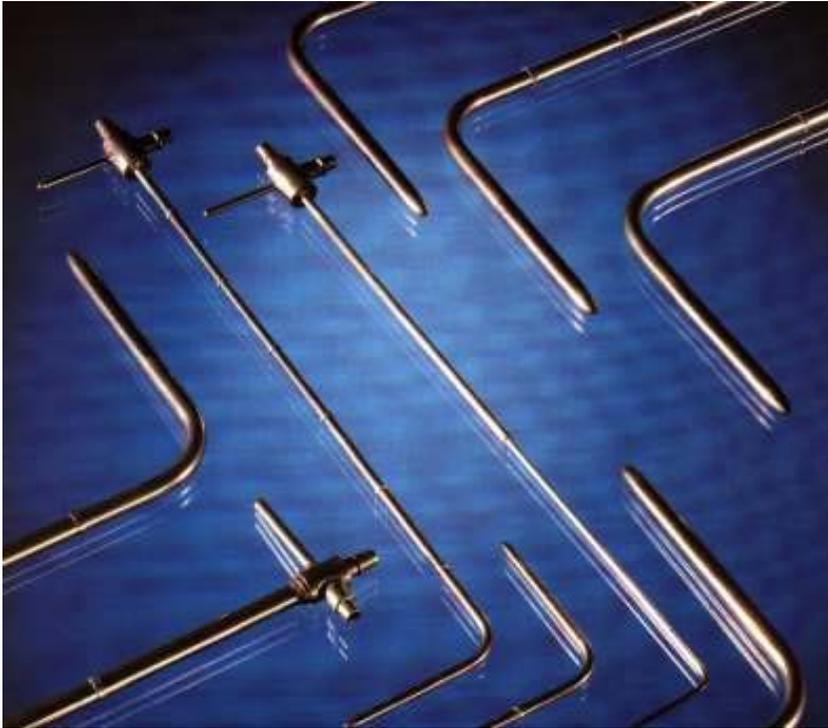
Instantané 2D (PIV)



Profils moyens



I - Tubes de Pitot



Tests en soufflerie

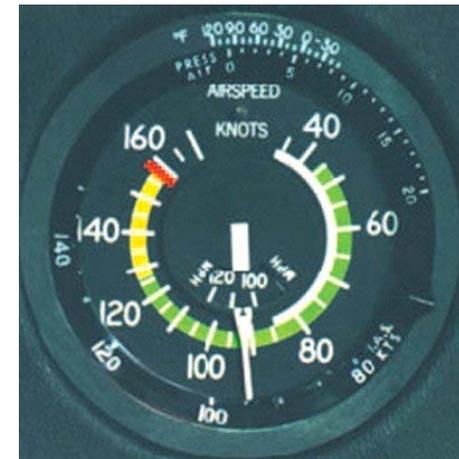
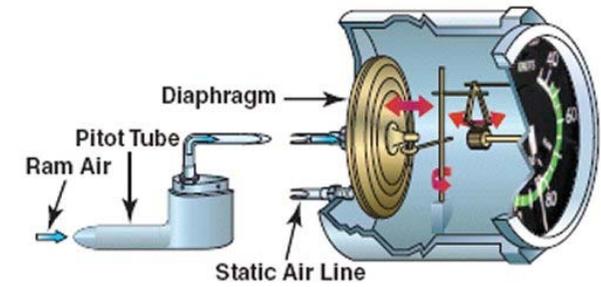


Tubes de Pitot pour l'aéronautique



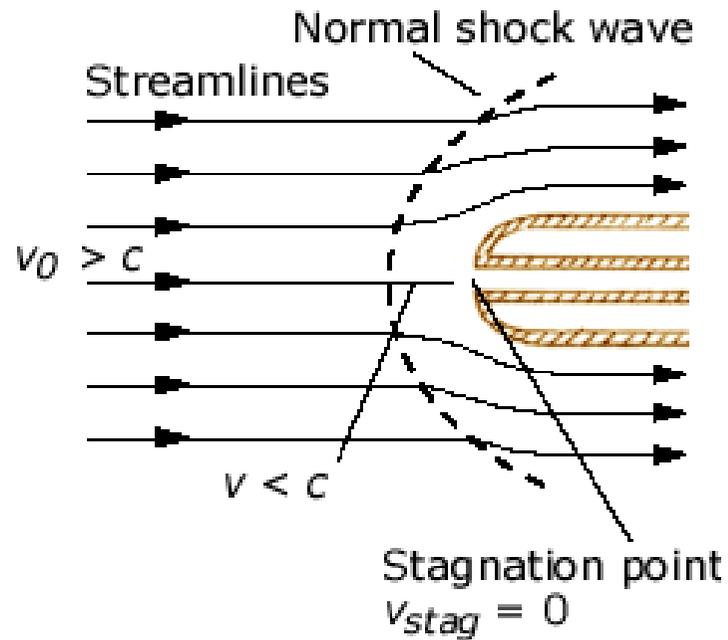
www.sensors.goodrich.com





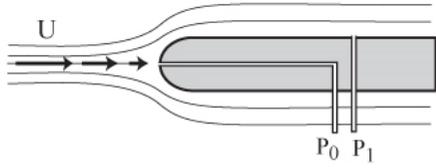
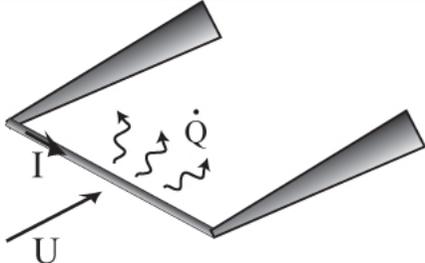
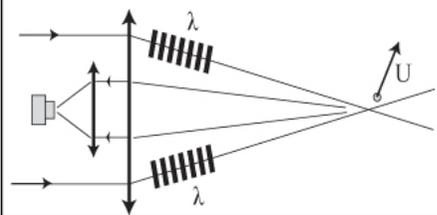
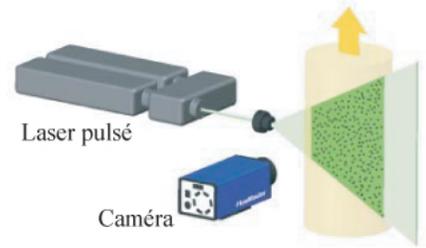


Tube de Pitot en écoulement supersonique

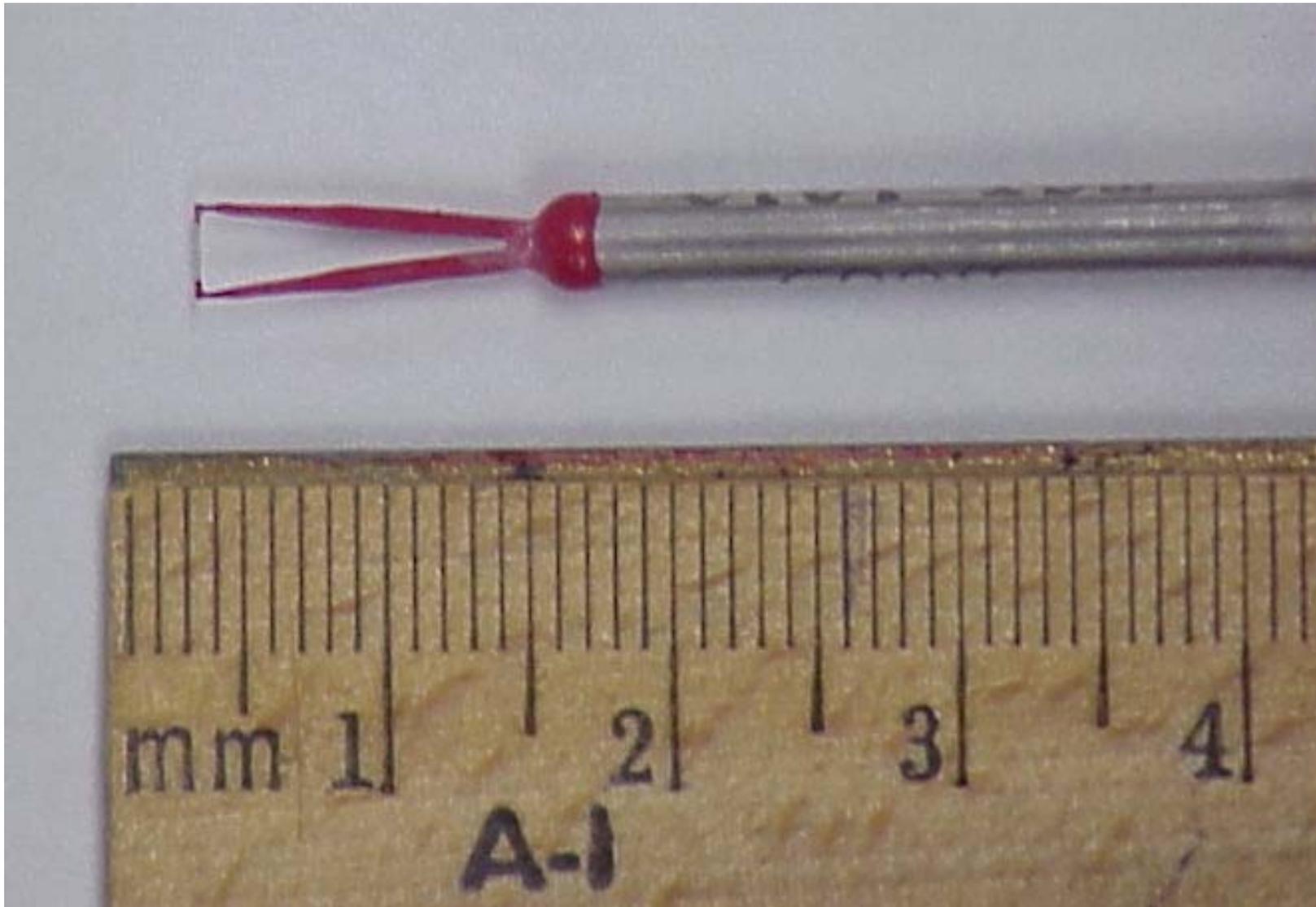


$$v = \sqrt{\frac{2\gamma}{\gamma-1} \frac{p_{static}}{\rho_{static}} \left[\left(\frac{p_{stagnation}}{p_{static}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]}$$

Les mesures de vitesse

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II – Anémométrie à fil chaud



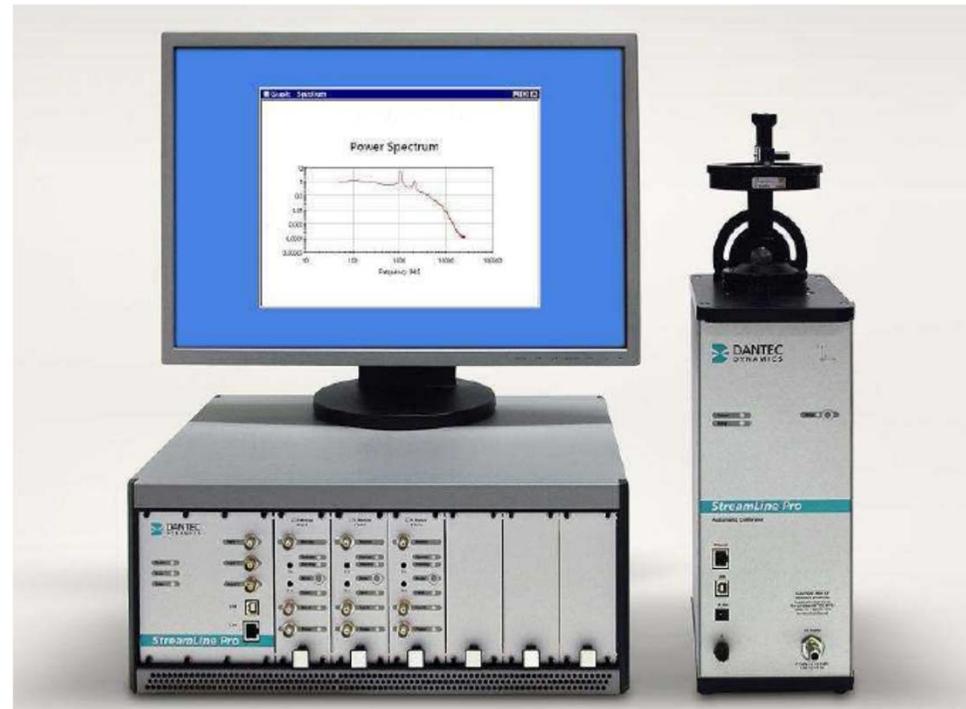
Modèle « de poche »
(vitesse moyenne)



www.omega.com

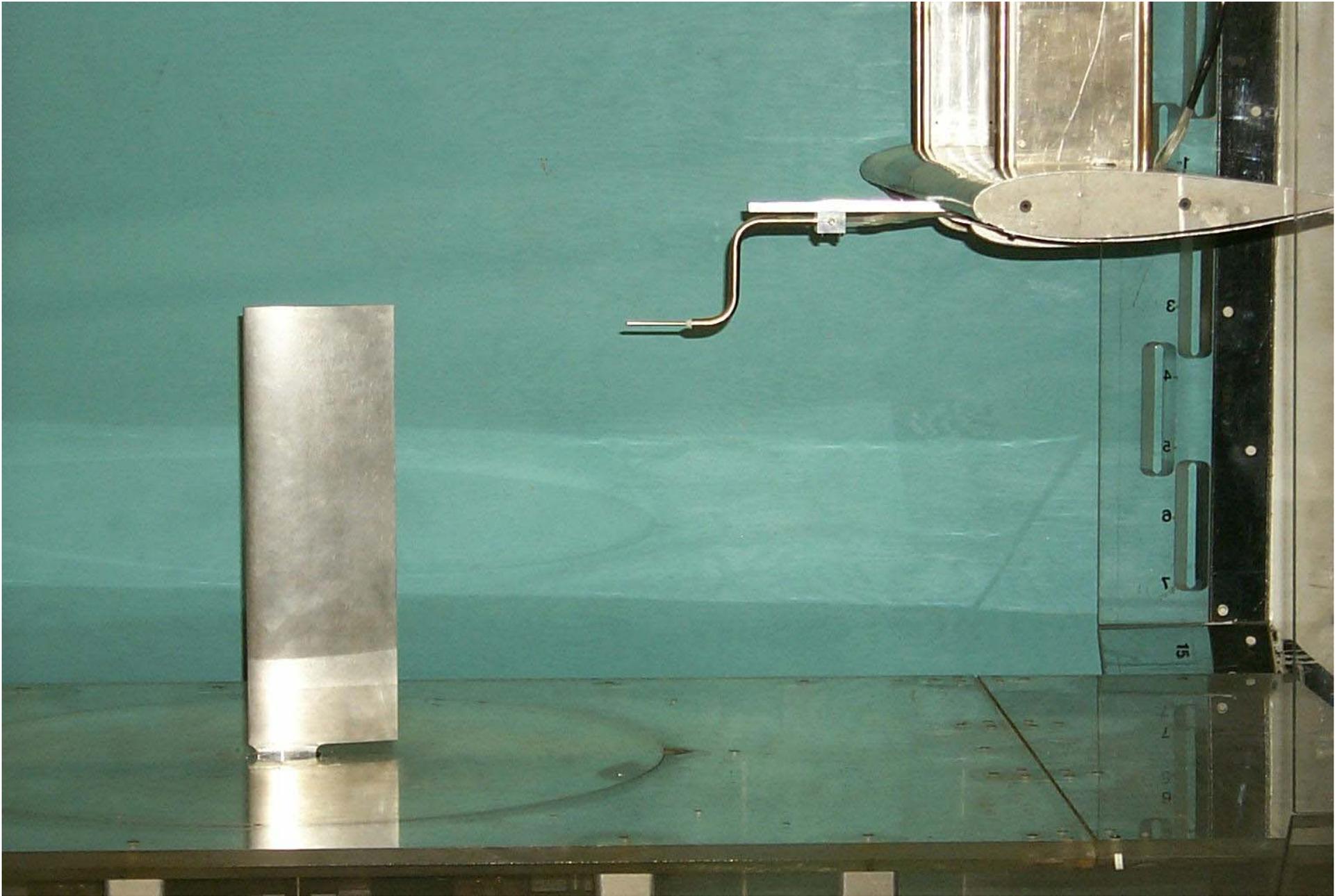
200-1000 euros

Modèle « laboratoire »
(vitesse instantanée)



www.dantecdynamics.com

1000 – 10 000 euros





(d'après Dantec)

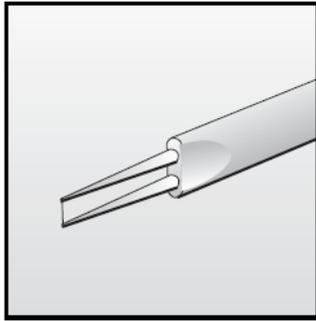


Fig. 1. 5 μm dia. platinum-plated tungsten wire, welded to the prongs.

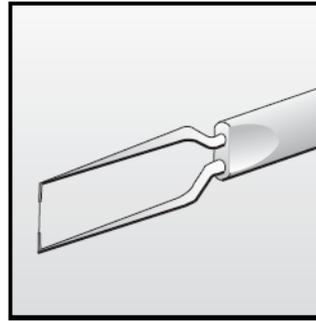


Fig. 2. 5 μm dia. platinum-plated tungsten wire, gold-plated at the ends to provide active sensor length of 1.25 mm.

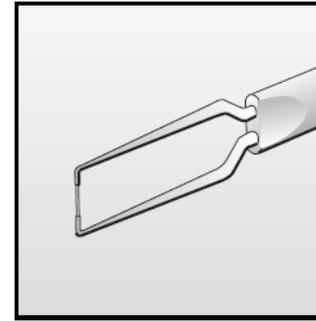


Fig. 3. 70 μm dia. quartz fiber with nickel film, gold plated at the ends to provide active sensor length of 1.25 mm.

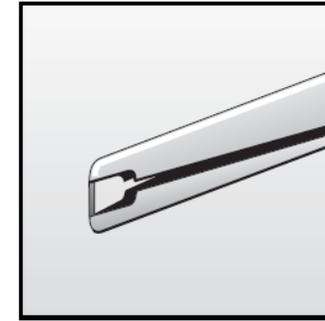


Fig. 4. Tip of wedge-shaped film probe.



Fig. 5. Tip of conical probe.

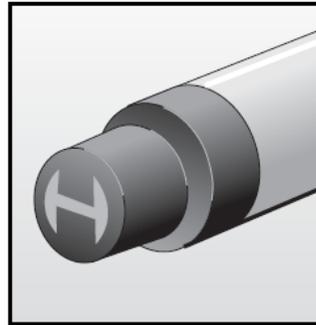


Fig. 6. Tip of flush-mounting probe.

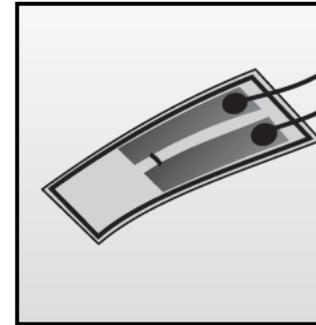


Fig. 7. Glue-on probe.

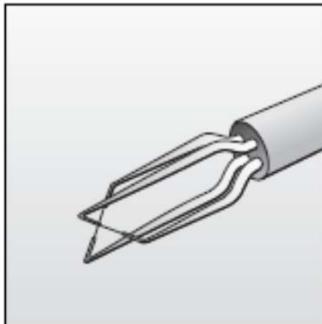


Fig. 9. Sensor arrangement of X-probe.

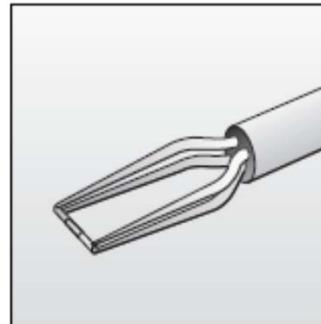


Fig. 10. Tip of split-fiber probe.

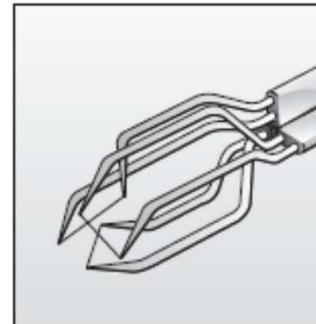
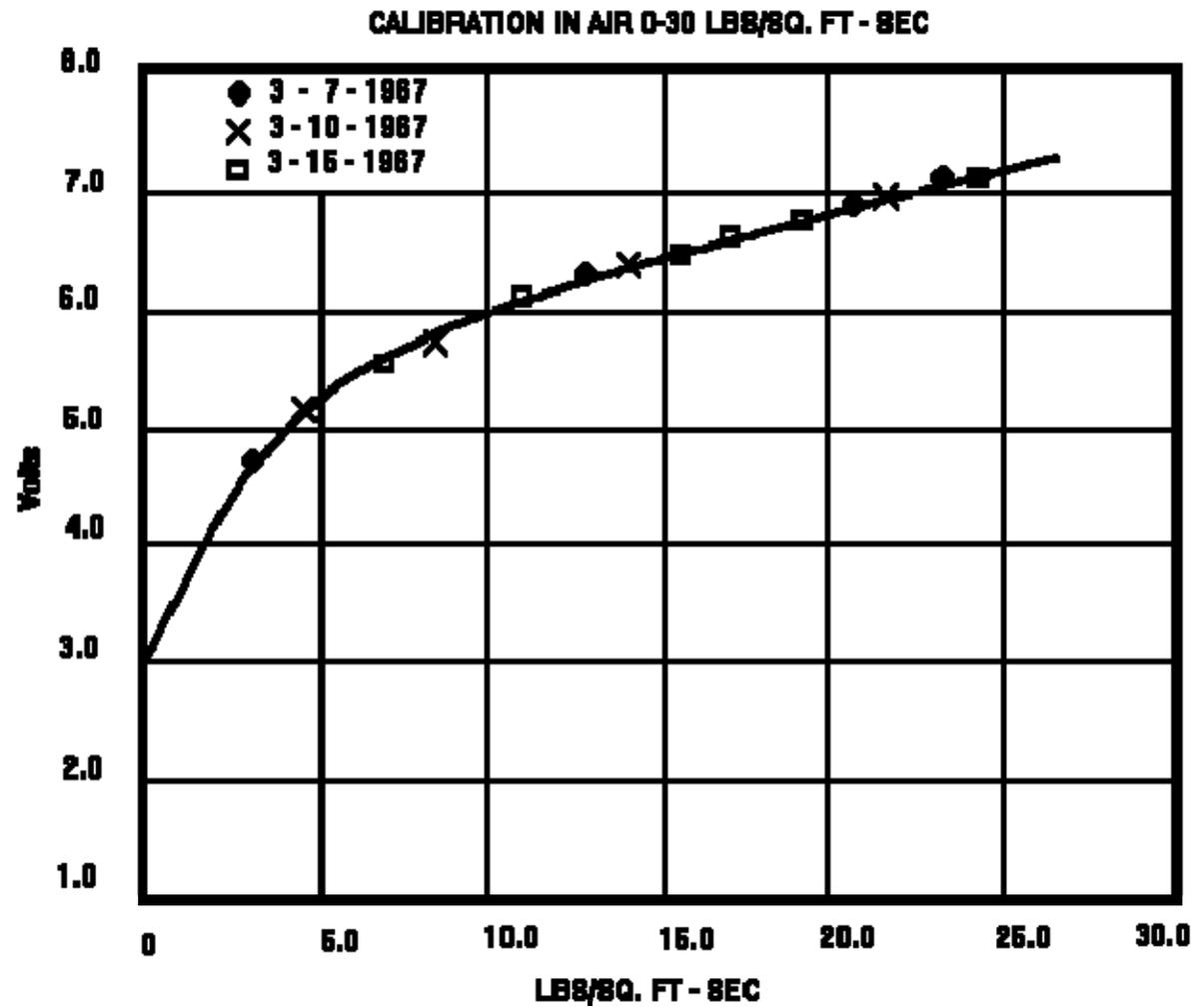
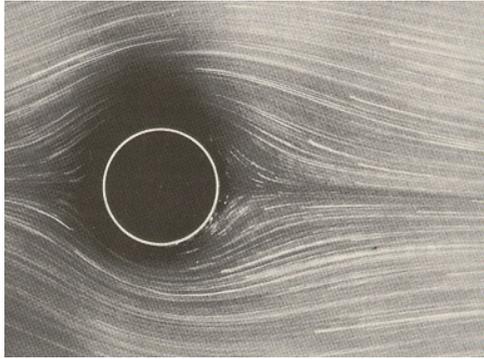


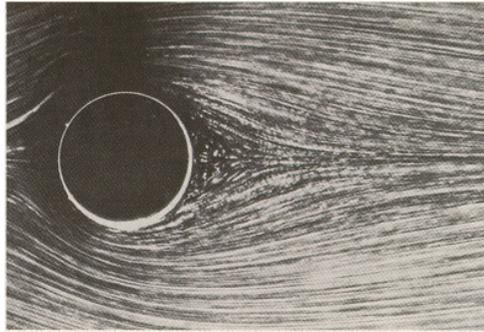
Fig. 11. Tip of triple-sensor probe.

Calibration : la loi de King $E(U)^2 = A + B U^{1/2}$

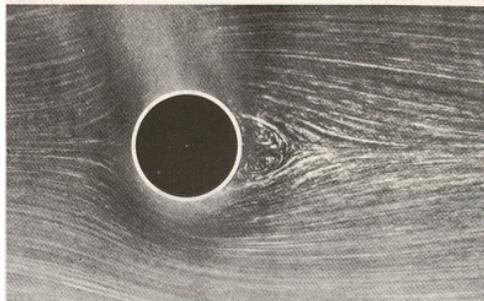




$Re = 1.5$



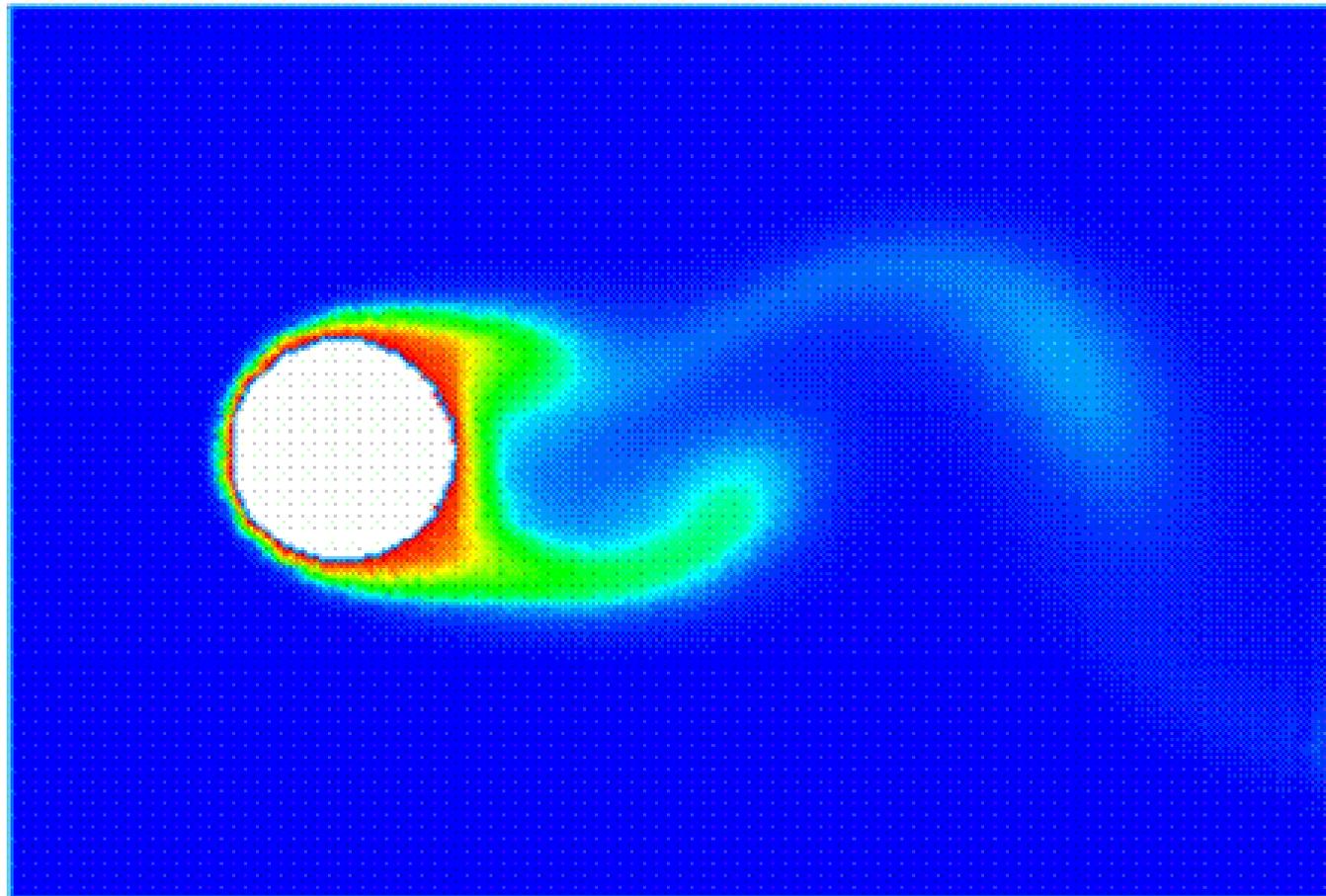
$Re = 10$



$Re = 13$



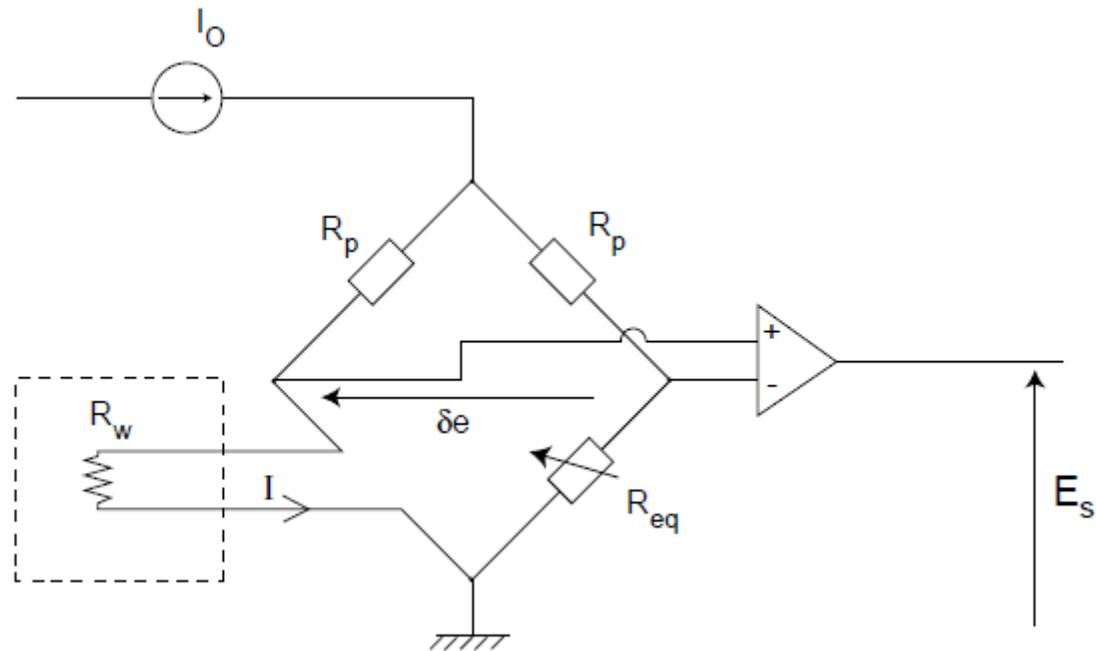
$Re = 26$



Convection of passive scalar, in this case temperature field in the vicinity of a heated cylinder.

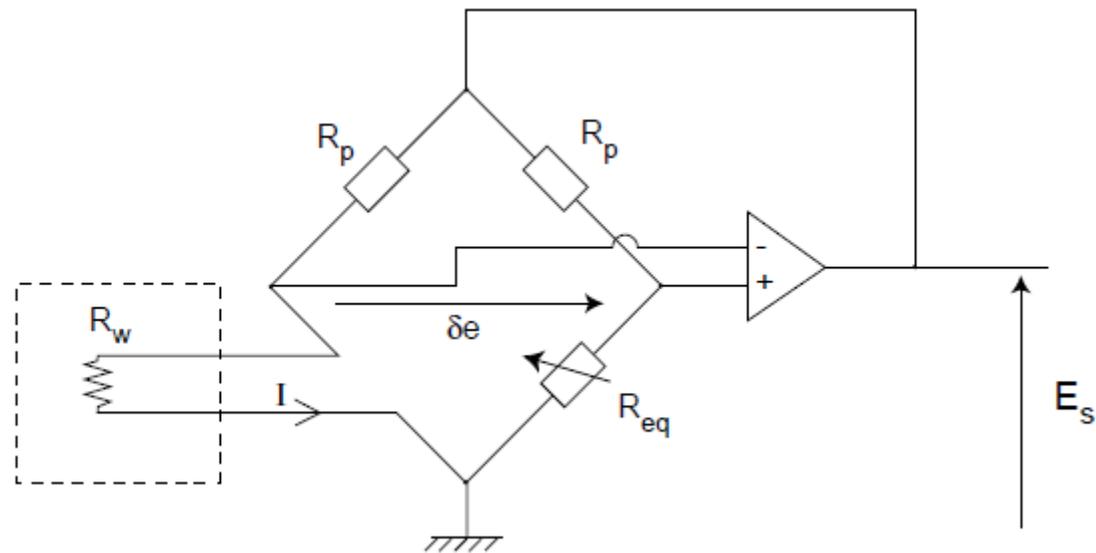
Asservissement d'un anémomètre à fil chaud

(1) Circuit à courant constant

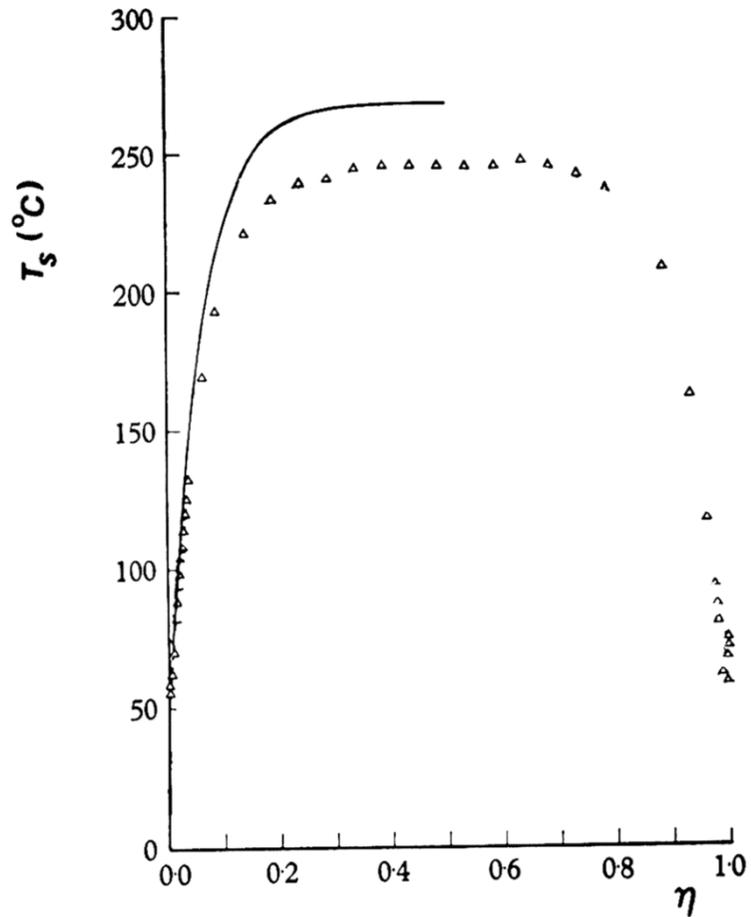


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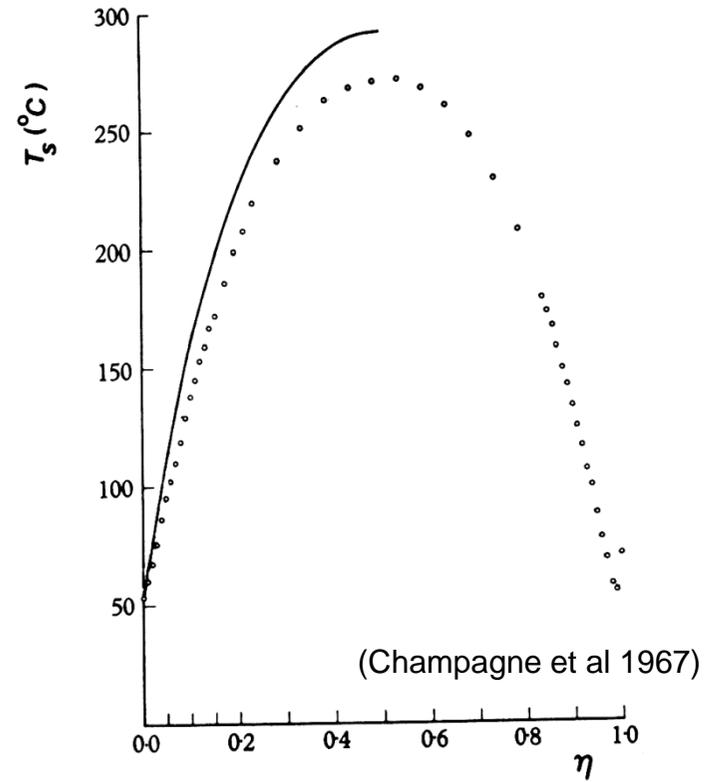
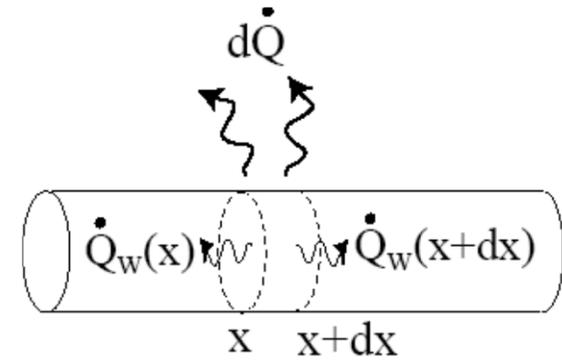
(2) Circuit à température constante



Effet de longueur finie :
profil de température le long du fil



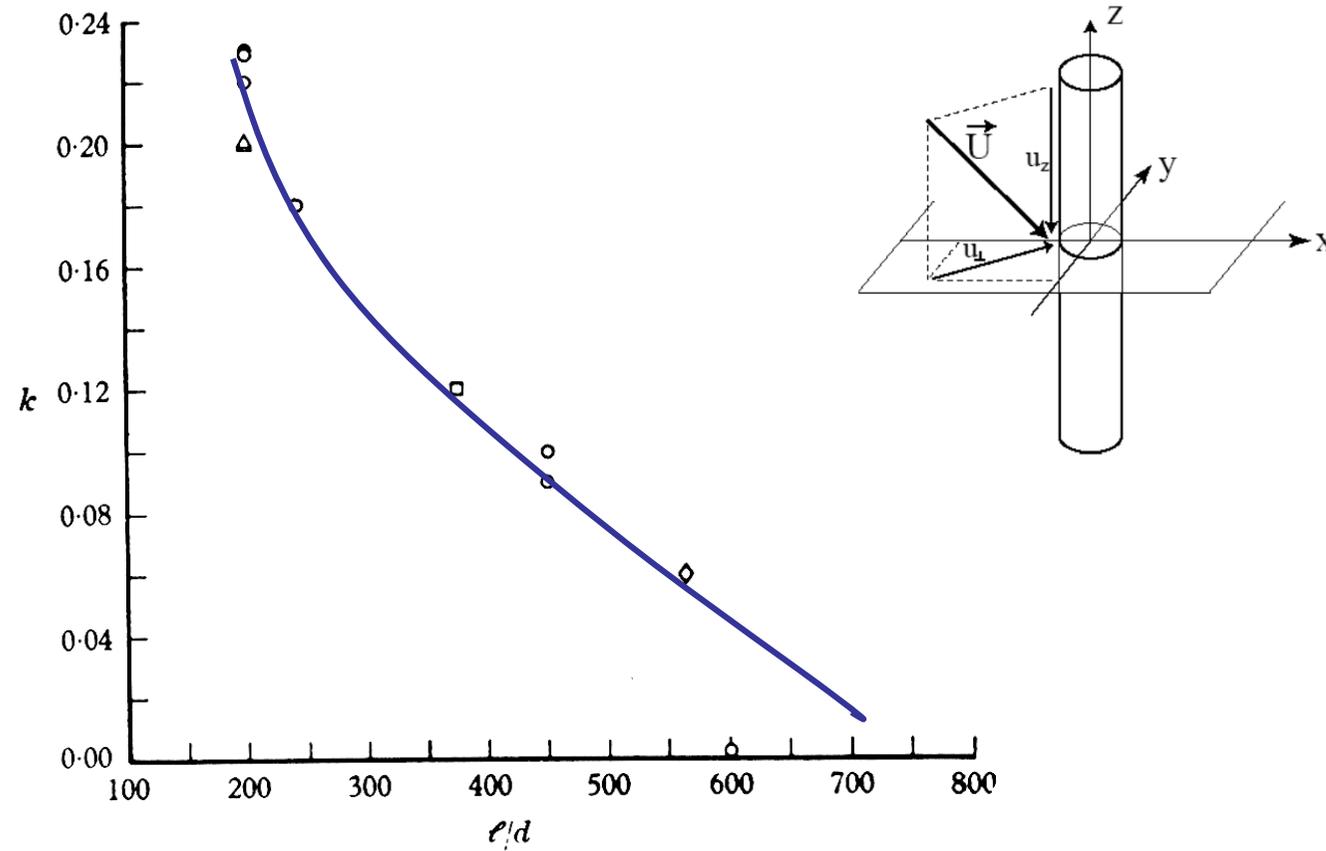
$l/d = 400$

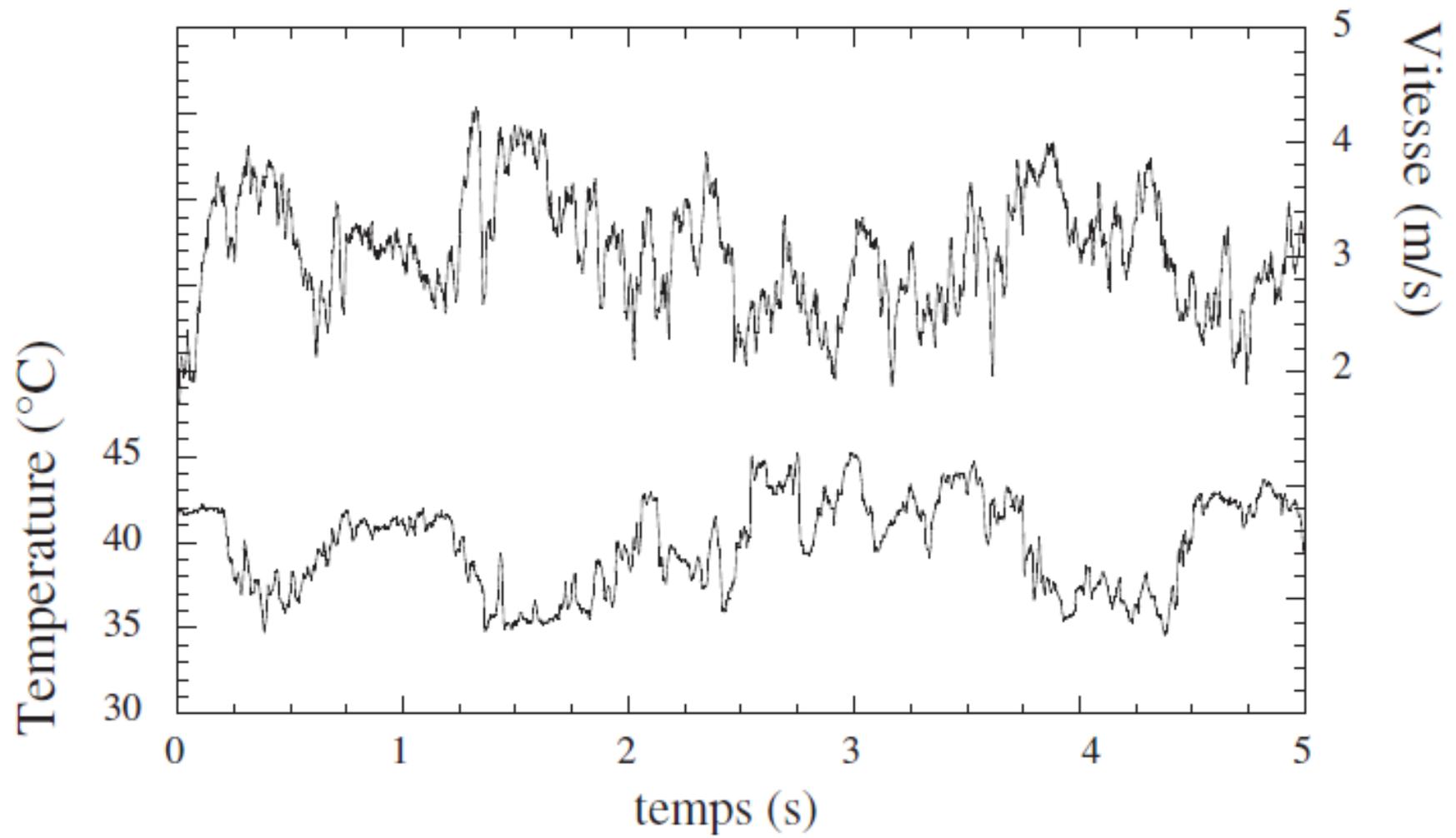


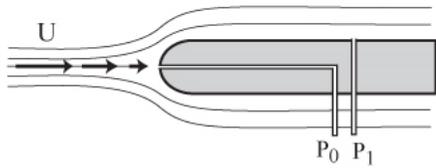
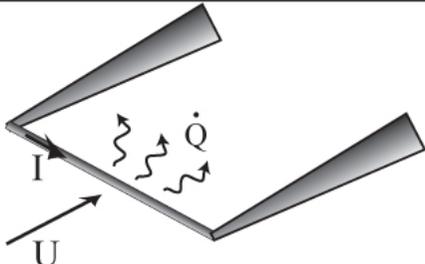
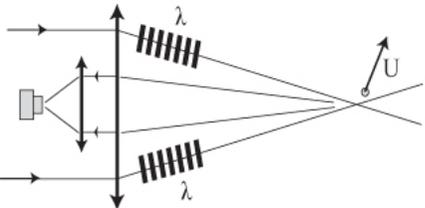
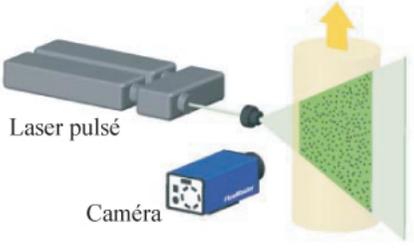
$l/d = 100$

Facteur de contamination angulaire

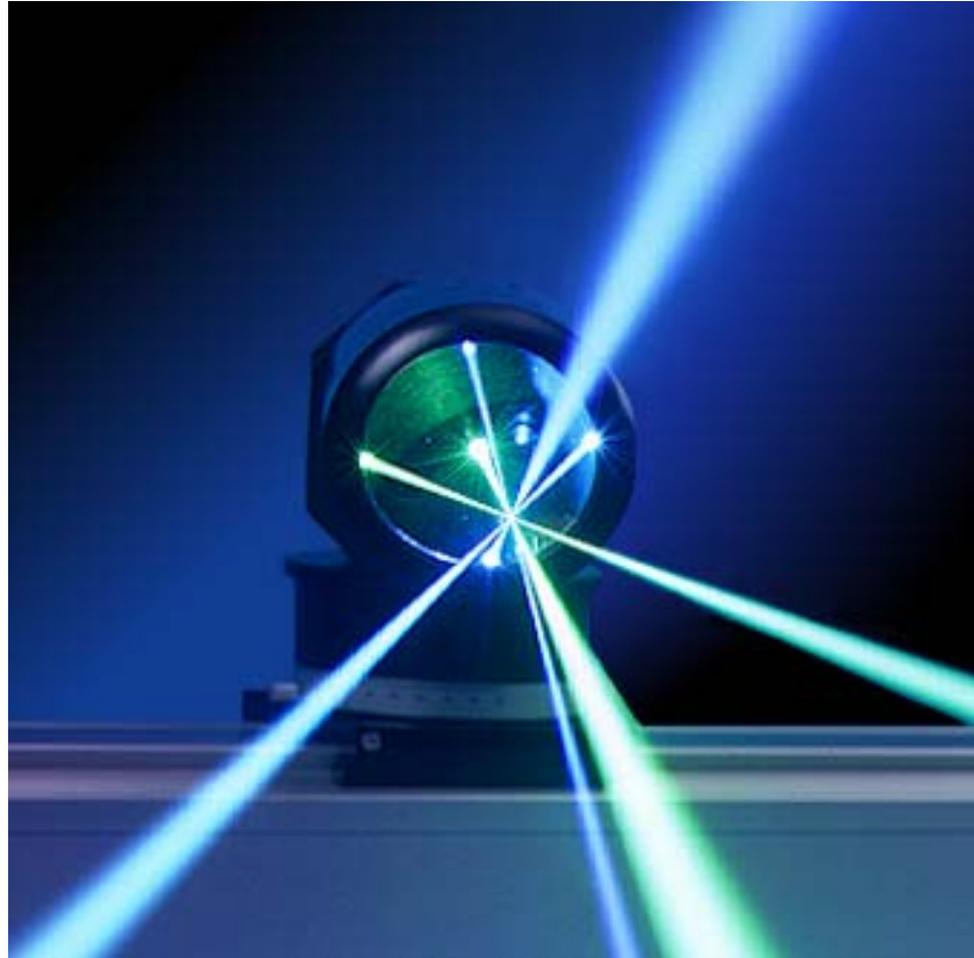
(Lomas, p. 24)



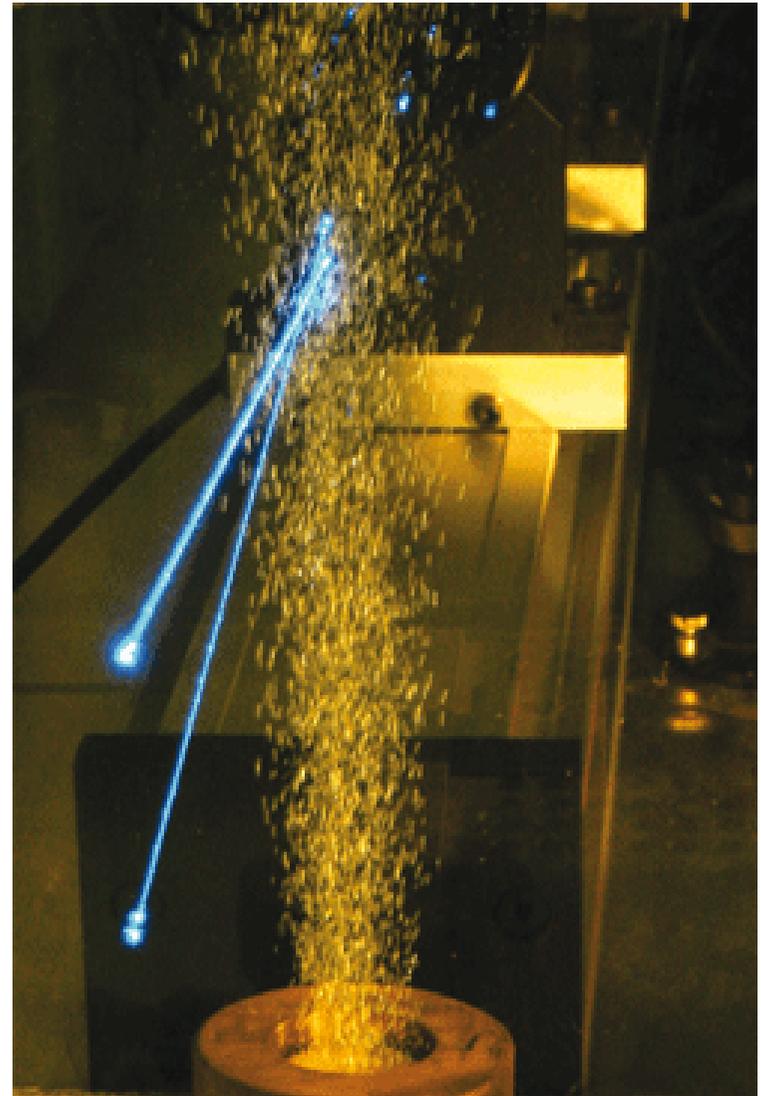
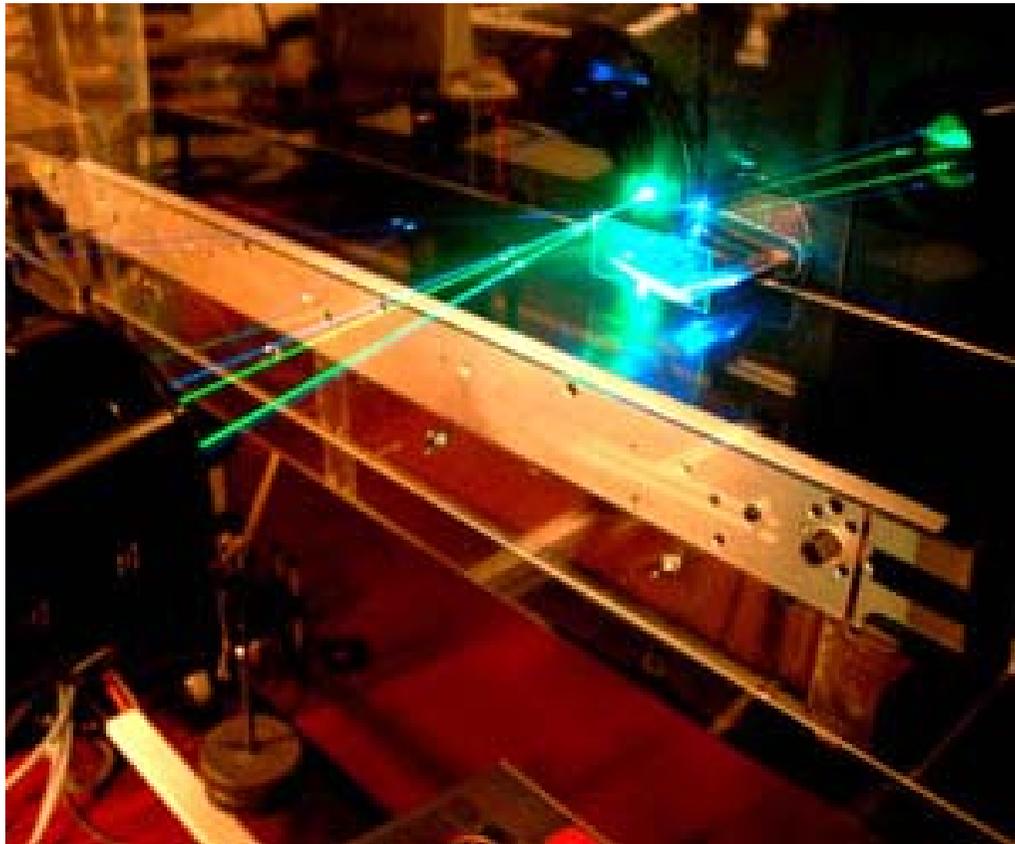


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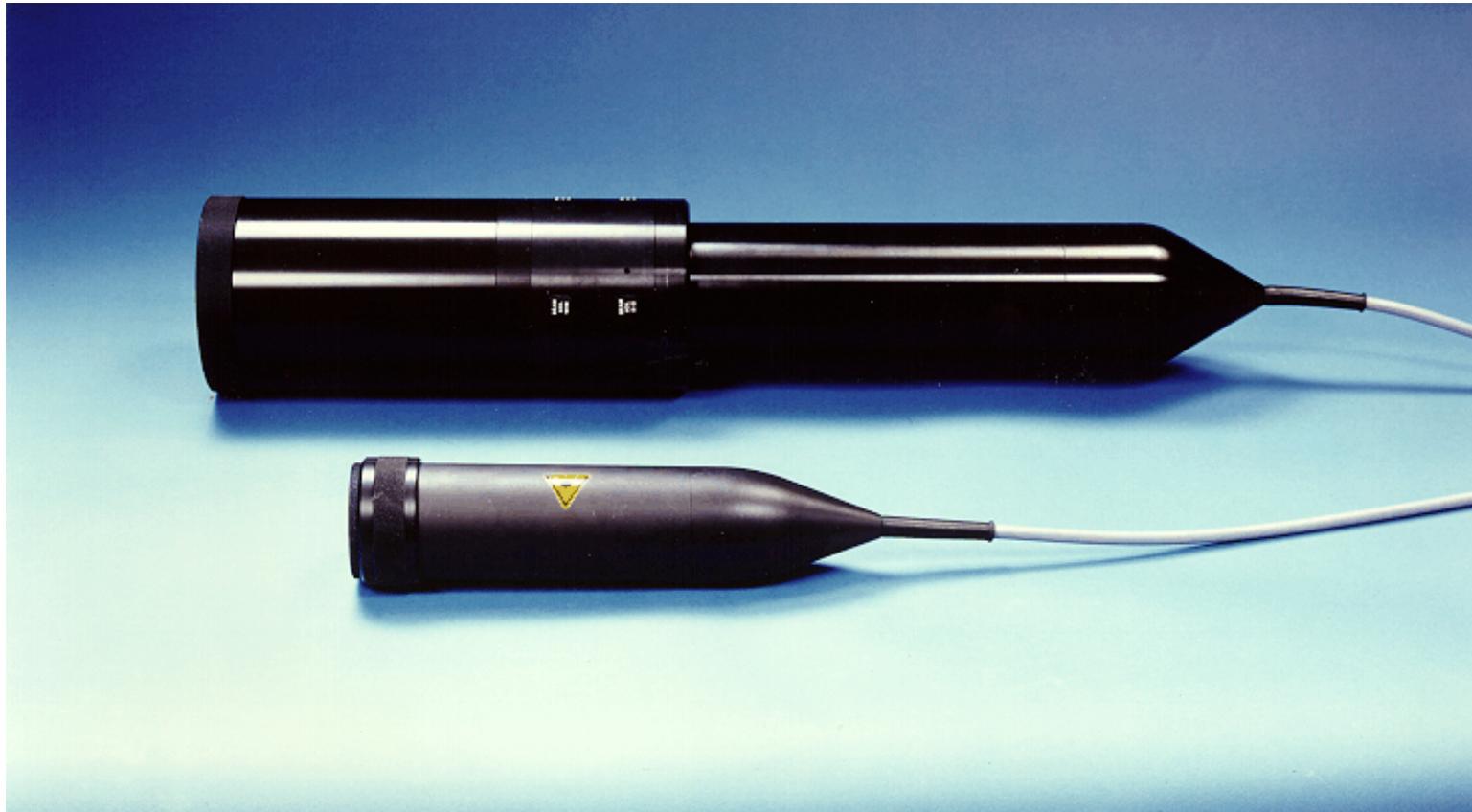
III. Laser Doppler Anemometry



(d'après doc. Dantec)



60 mm and 85 mm *FiberFlow* probes



(d'après doc. Dantec)

Measurement of flow in a valve model

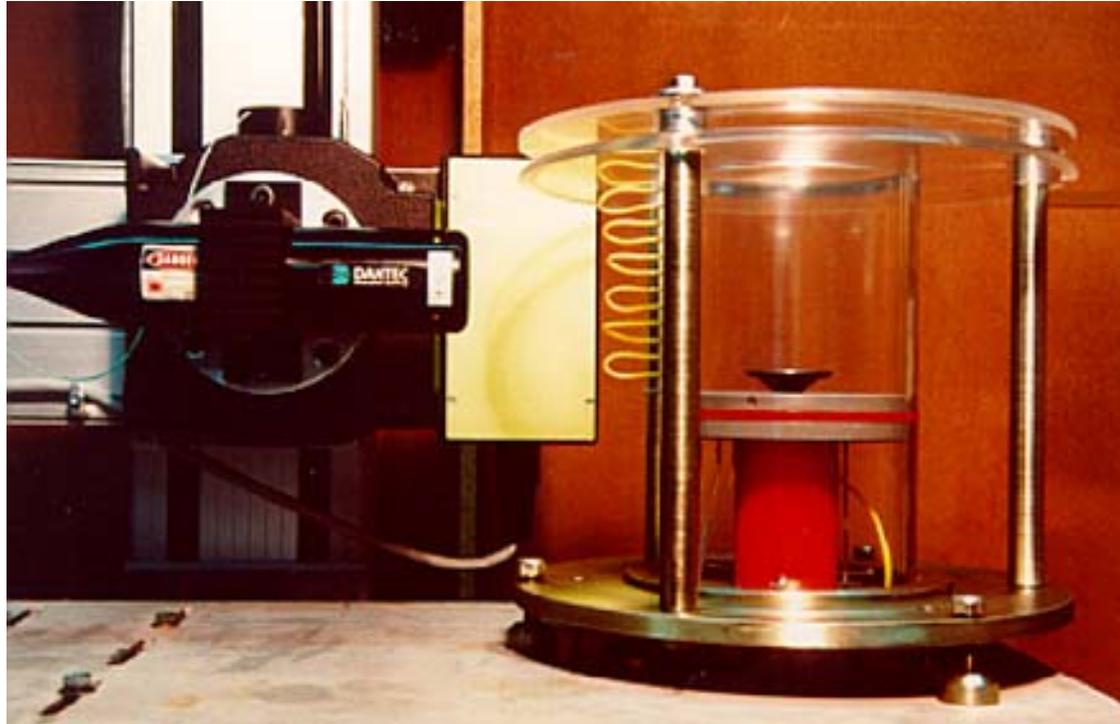
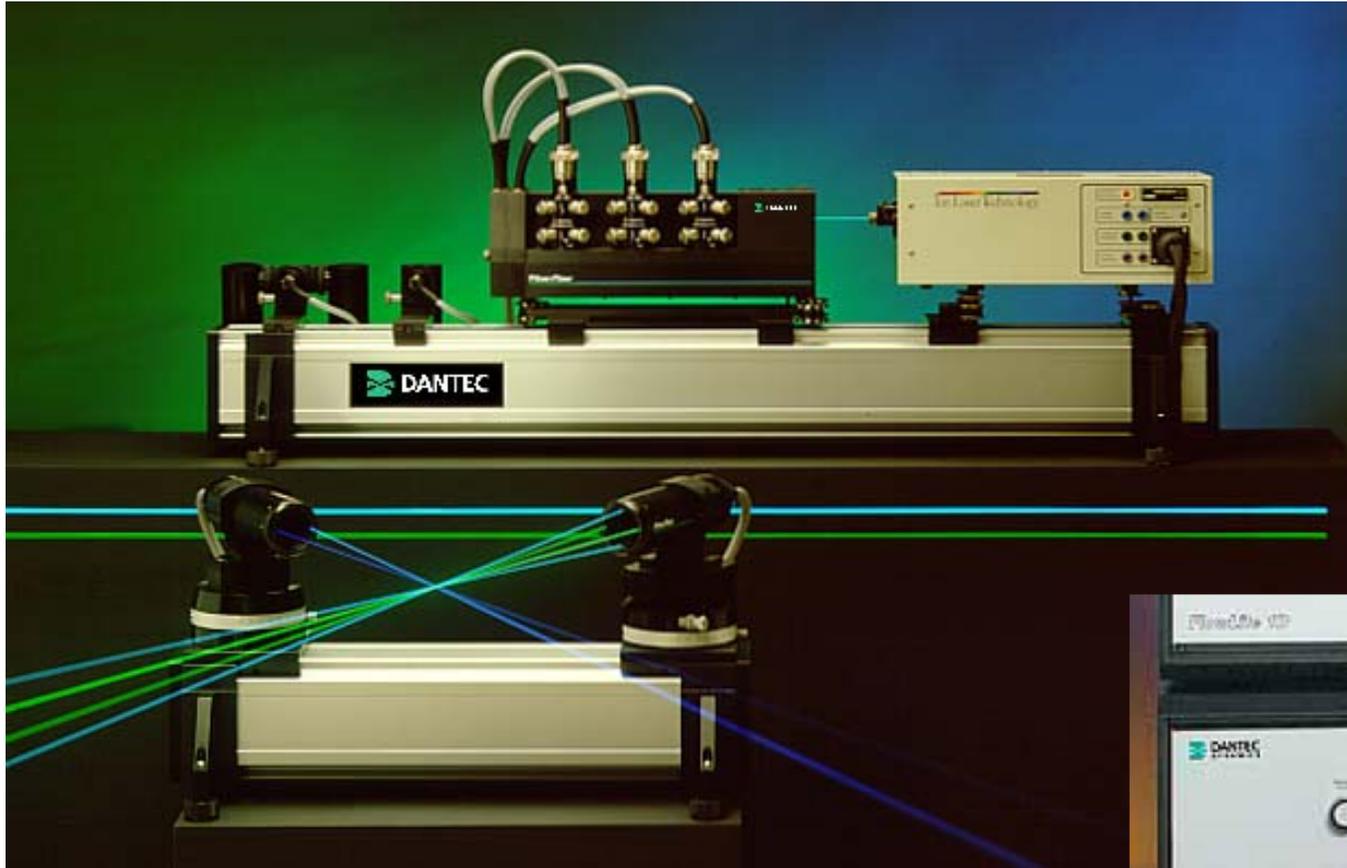


Photo courtesy of Westsächsische Hochschule Zwickau, Germany

Mesures de 3 composantes



(d'après doc. Dantec)

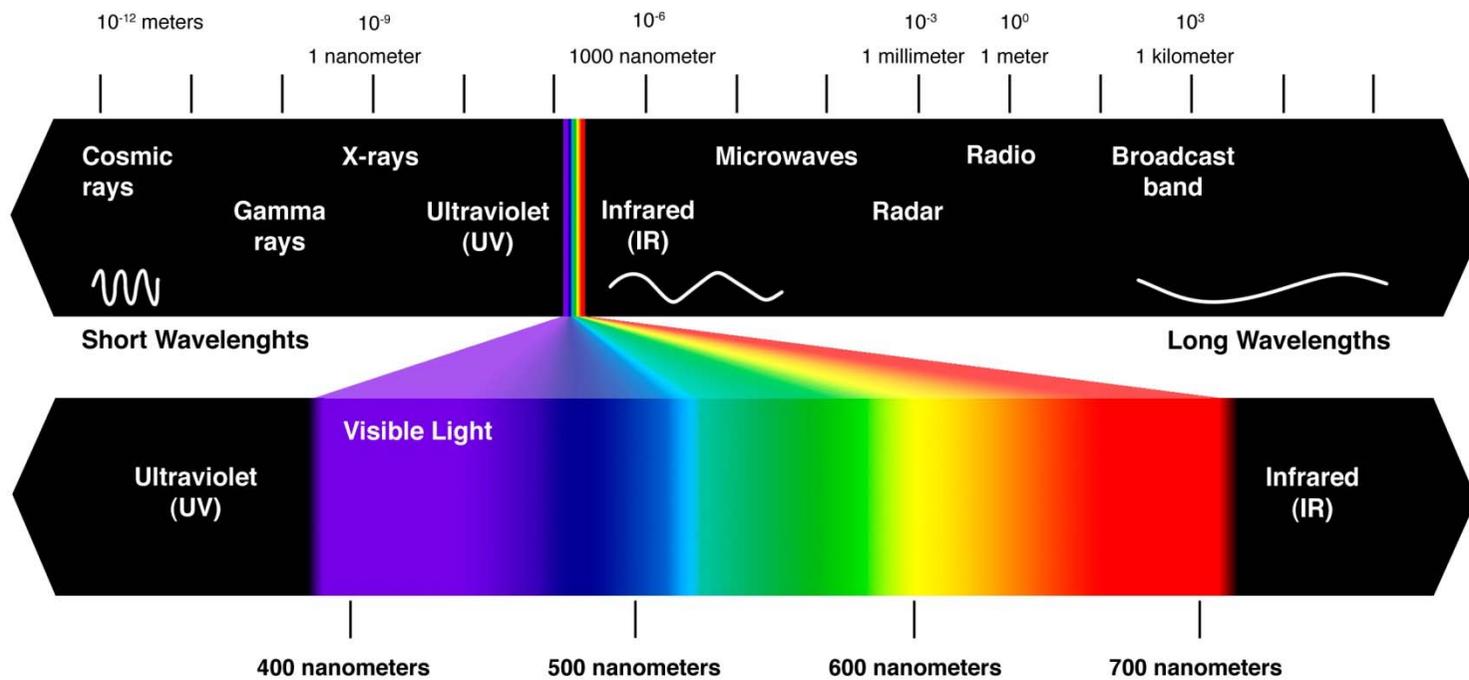
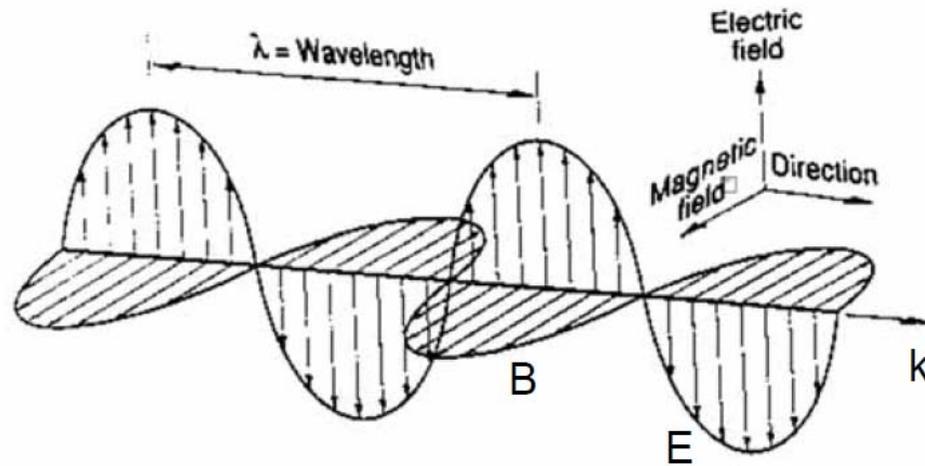


The small integrated 3D *FiberFlow* probe

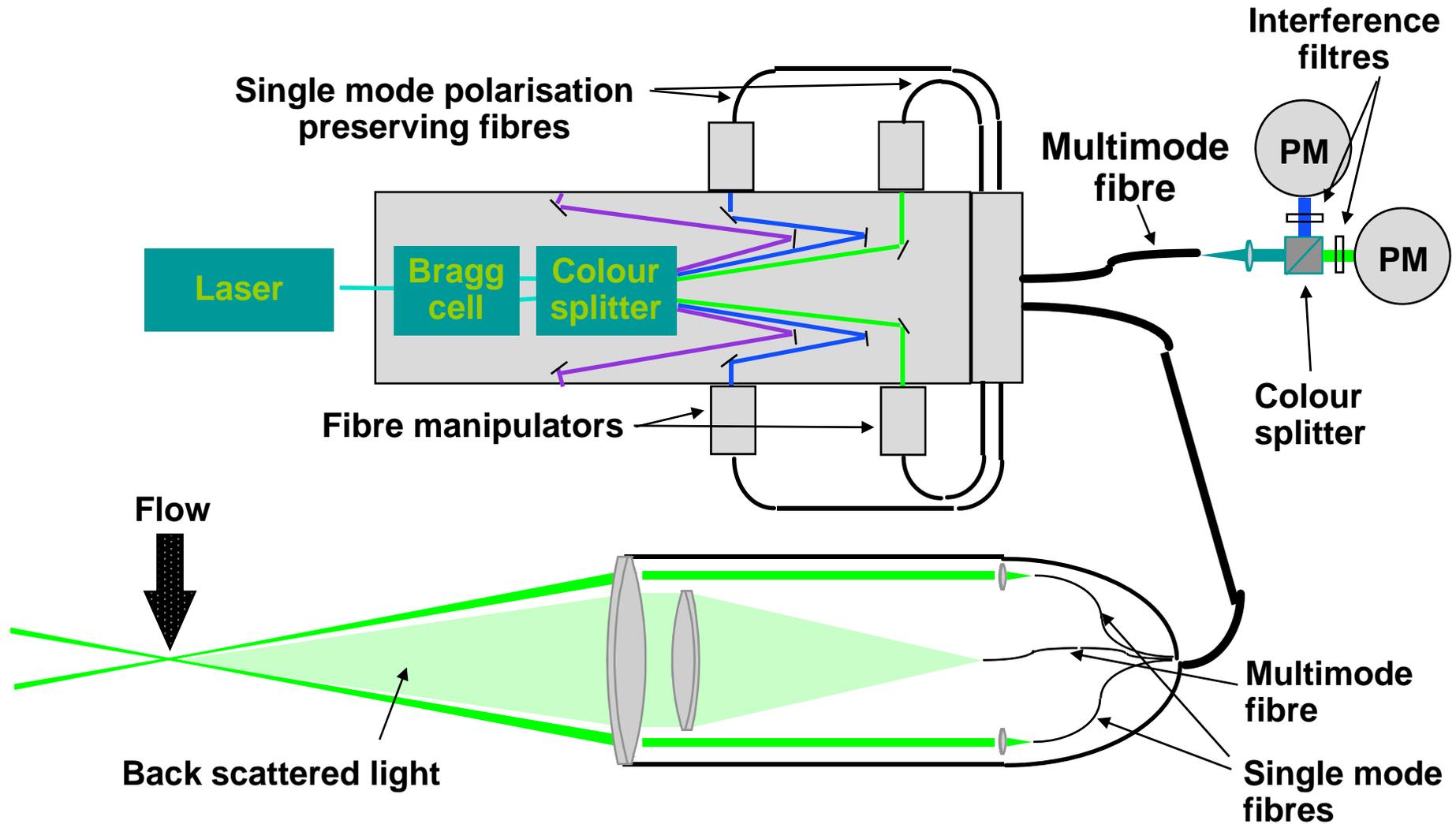


(d'après doc. Dantec)

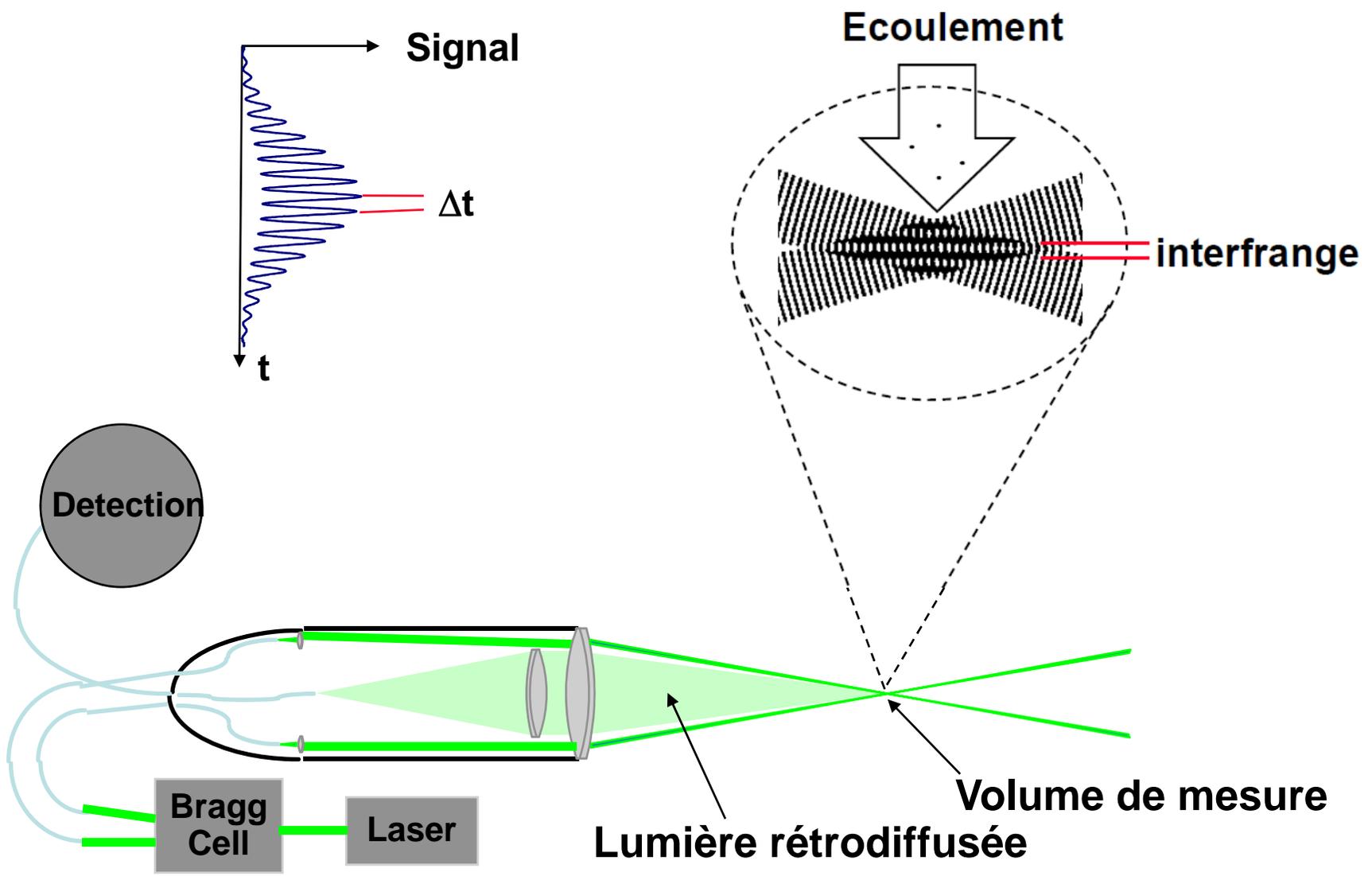
Lumière visible



Backscatter configuration

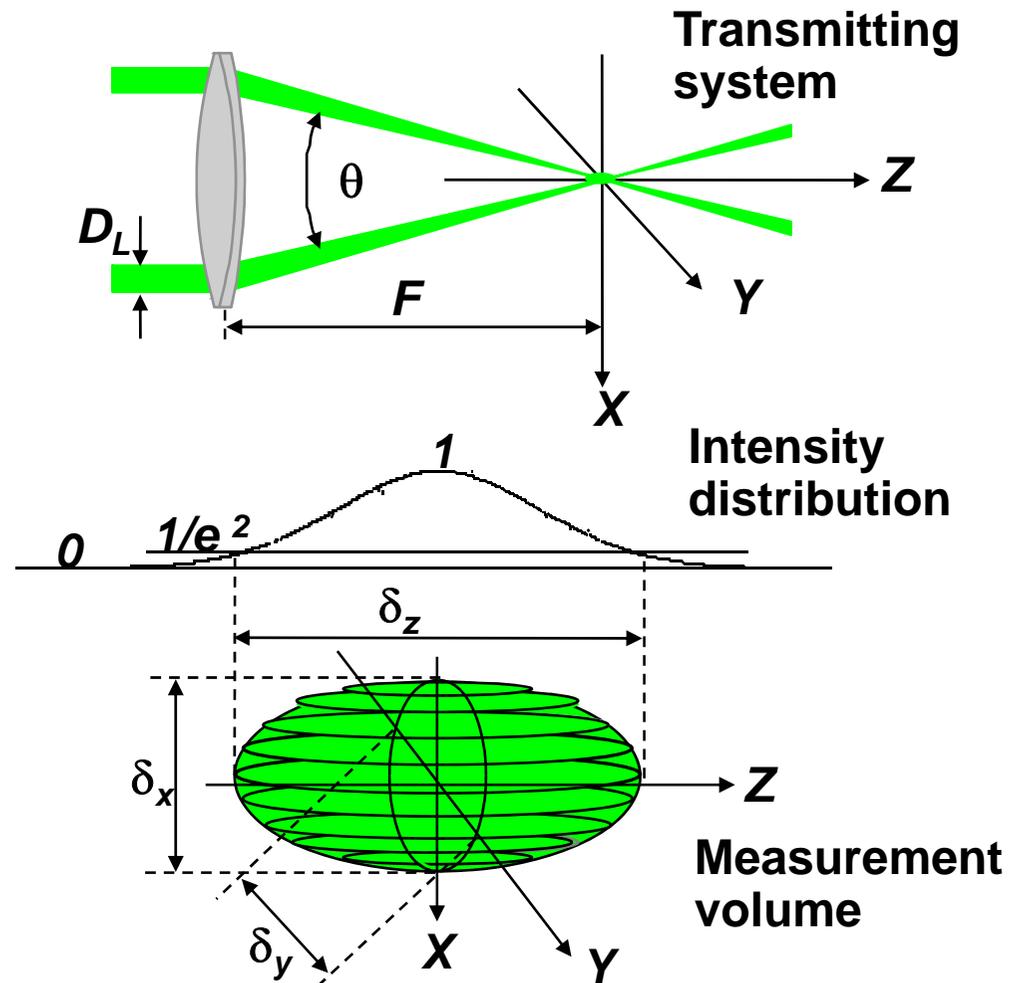


Montage en rétrodiffusion : modèle des franges

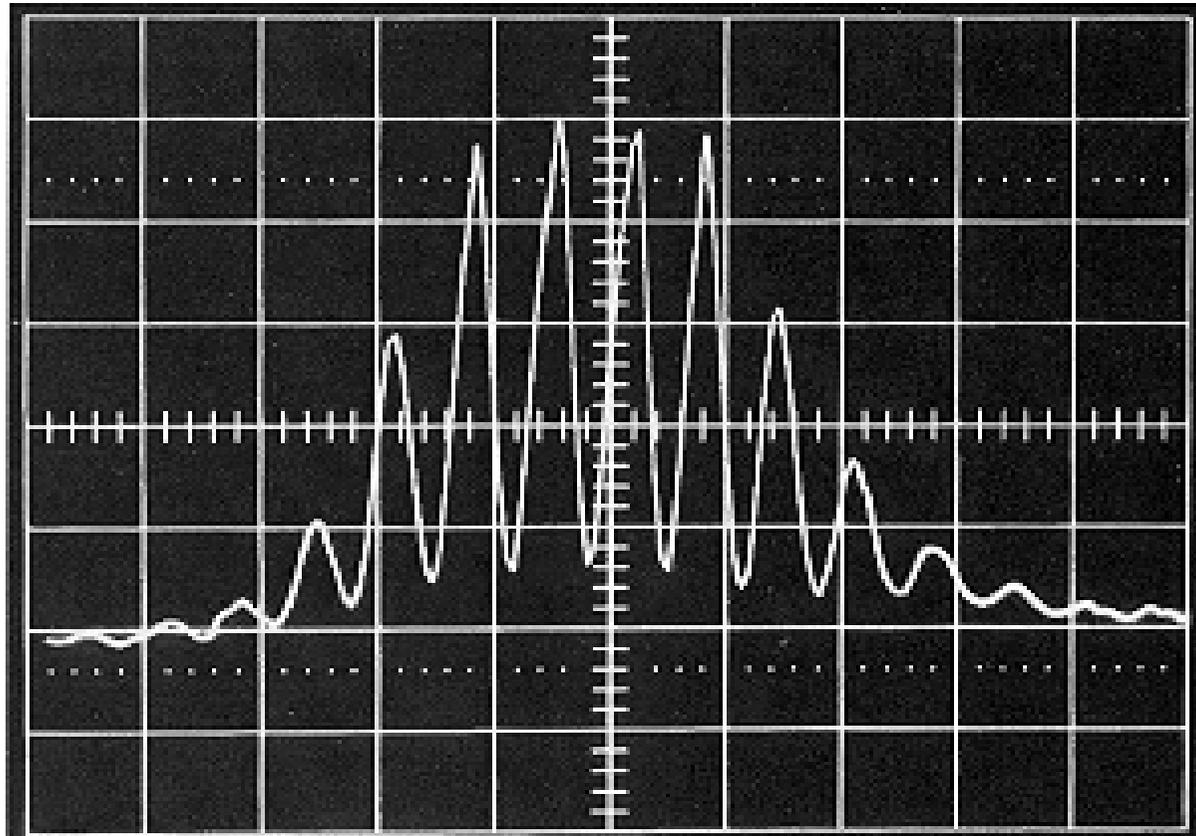


Measurement volume

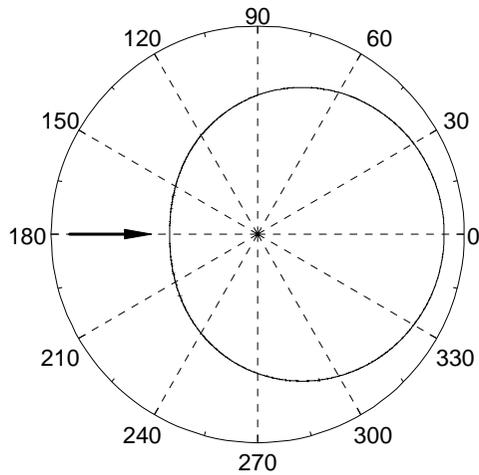
- The transmitting system generates the measurement volume
- The measurement volume has a Gaussian intensity distribution in all 3 dimensions
- The measurement volume is an ellipsoid
- Dimensions/diameters δ_x , δ_y and δ_z are given by the $1/e^2$ intensity points



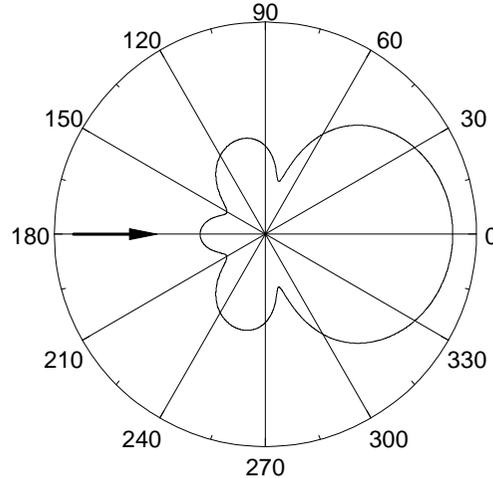
Exemple de signal



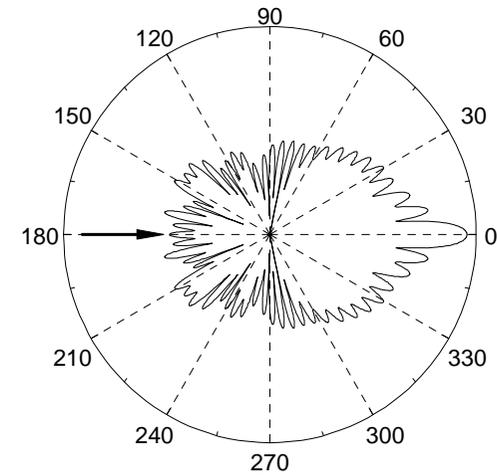
Seeding: scattered light intensity



$$d_p \approx 10\lambda$$



$$d_p \approx 1.0\lambda$$



$$d_p \approx 0.2\lambda$$

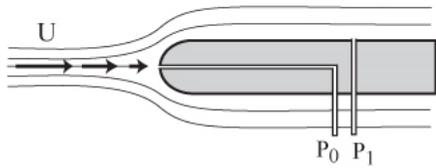
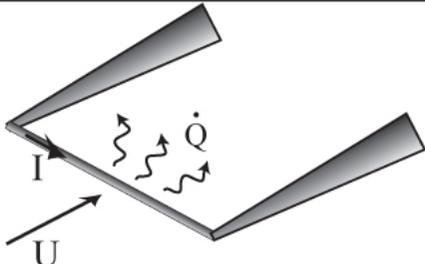
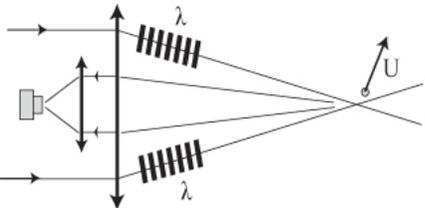
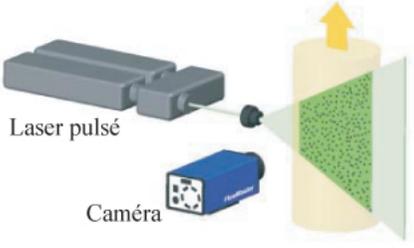
- Polar plot of scattered light intensity versus scattering angle
- The intensity is shown on a logarithmic scale

Ensemencement

Particle Frequency Response

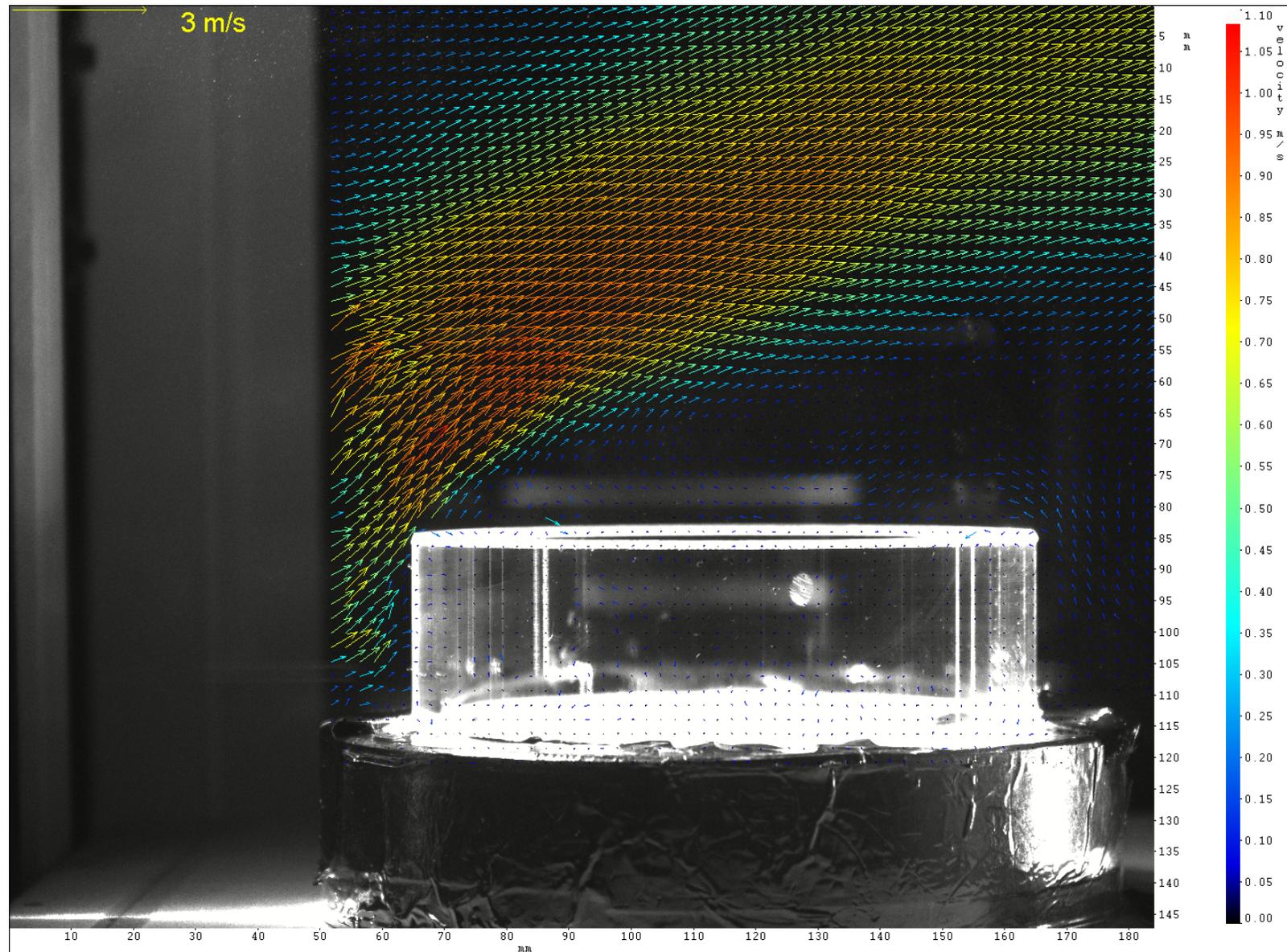
$$\frac{d}{dt} U_p = -18 \frac{\nu}{d_p^2} \frac{U_p - U_f}{\rho_p / \rho_f}$$

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

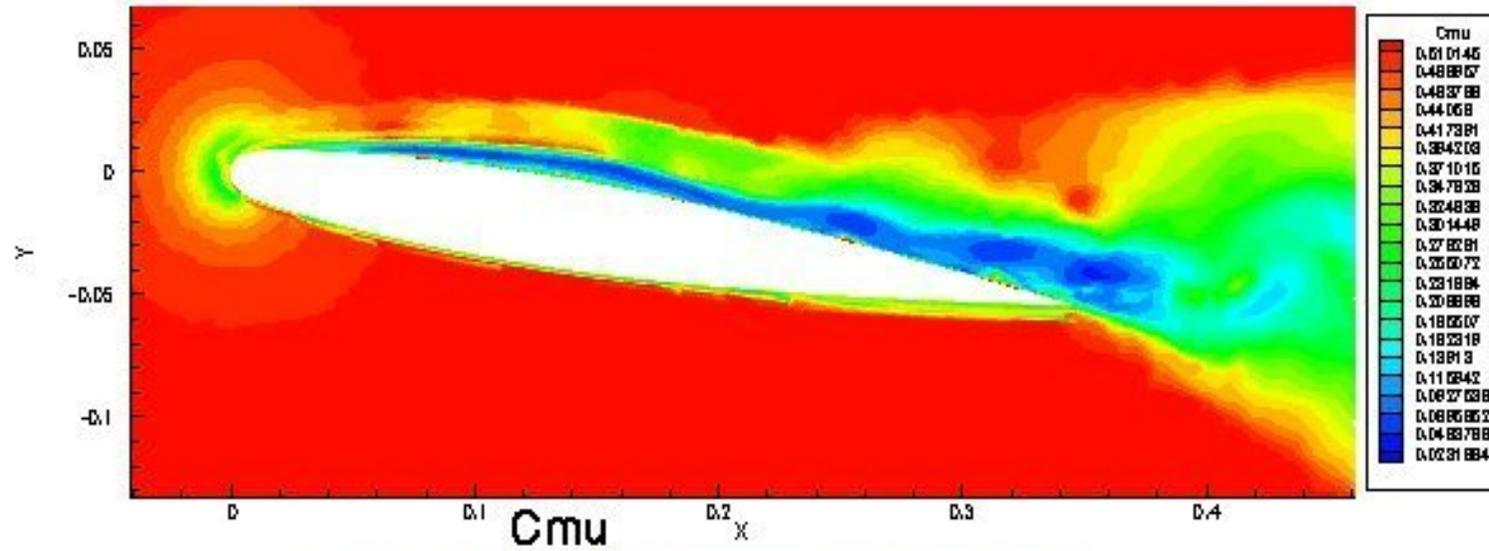
	TUBE DE PITOT	ANEMOMETRE A FIL CHAUD (HOT WIRE ANEMOMETRY)	ANEMOMETRE LASER DOPPLER (LASER DOPPLER VELOCIMETRY, LDV)	VELOCIMETRIE PAR IMAGES DE PARTICULES (PIV)
Schéma				
Principe	Mesure de 2 pressions (statique et dynamique) ? Bernouilli $U = \sqrt{2(P_d - P_s) / \rho}$	Mesure de la puissance RI^2 dissipée par un fil chauffé.	Mesure (par interférométrie) du décalage Doppler sur particule diffusante.	Mesure du déplacement de particules entre deux images (méthode de corrélations)
Avantages	Mise en œuvre très simple, bon marché (~ 1 k€) Idéal pour profils de vitesse moyenne	Excellente résolution spatiale et temporelle (idéal pour mesures de fluctuations turbulentes). Mise en œuvre assez simple, coût modéré (~ 10 - 20 k€).	Non intrusif. Calibration linéaire. Très bonne résolution spatiale et temporelle (idéal pour mesures de fluctuations turbulentes). Possibilité mesure plusieurs composantes.	Non intrusif. Champ 2D instantané.
Inconvénients	Très intrusif. Résolution spatiale & temporelle faible.	Intrusif. Fragile Calibration non linéaire Contaminations (fluct° température)	Accès optique (fluide transparent). Nécessite ensemencement. Réglages délicats. Cher (50-100 k€)	Accès optique (fluide transparent). Nécessite ensemencement. Mauvaise résolution temporelle. Cher (70 - 100 k€)

Ecoulement dans une hotte aspirante

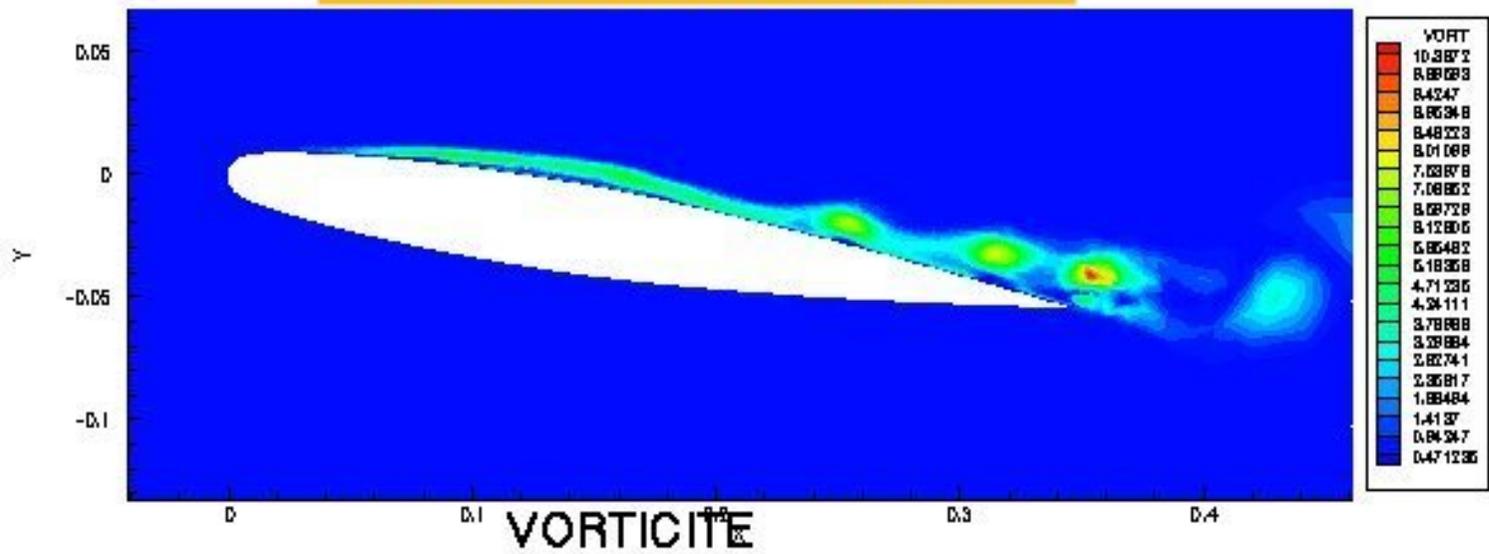
FAST, 2003



Profil ONERA D 9deg 40m/sec ldp insta

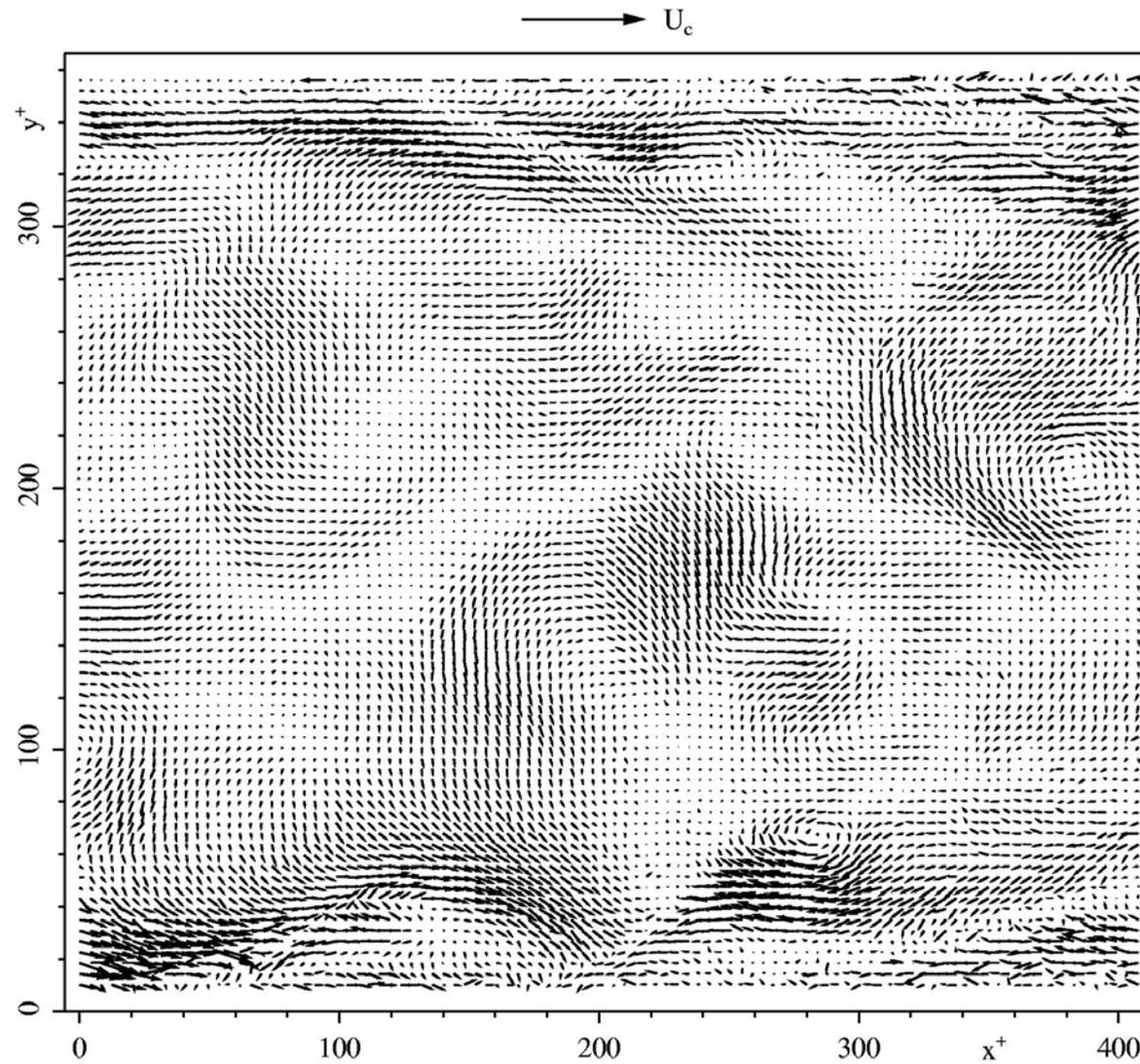


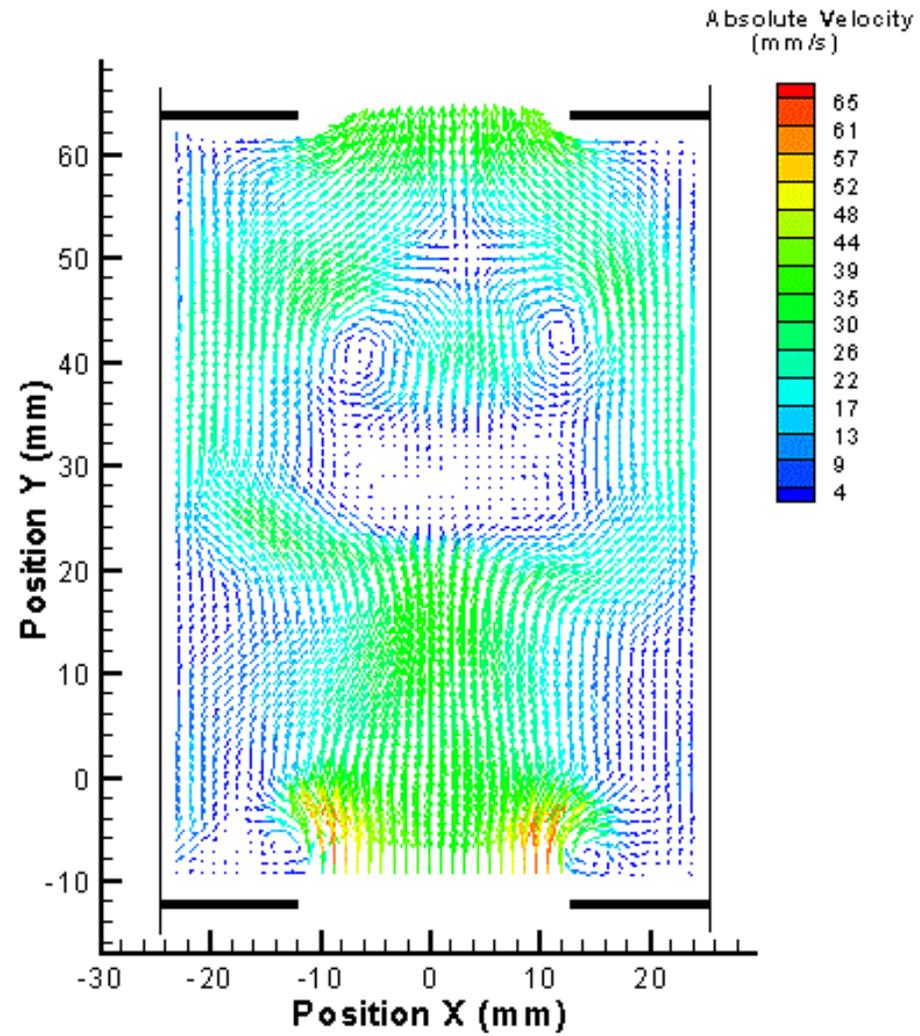
EMT2(IMFT)/Dassault-Aviation

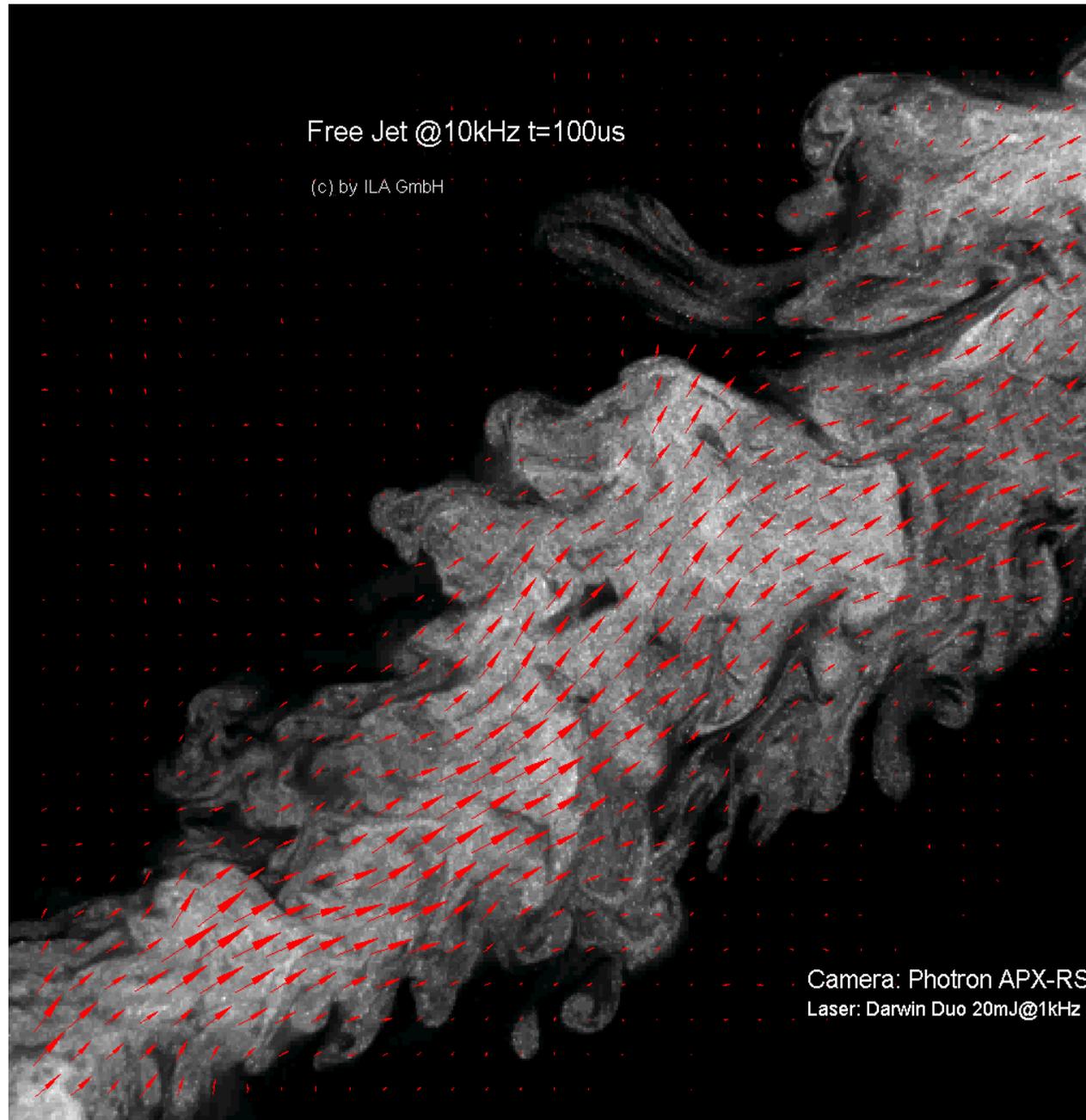


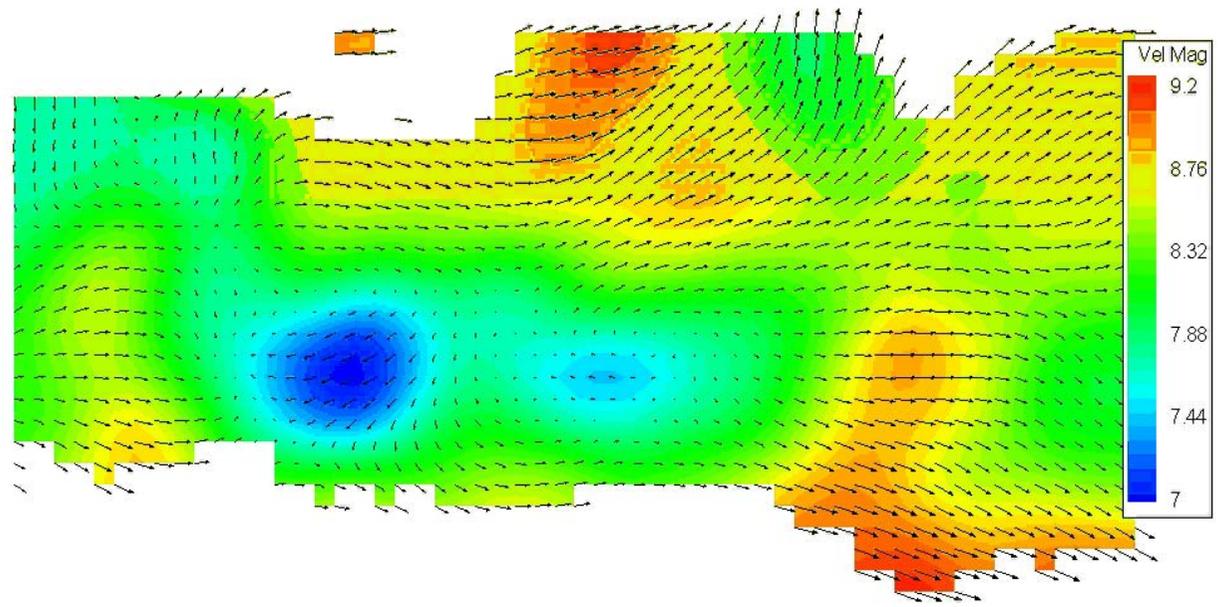
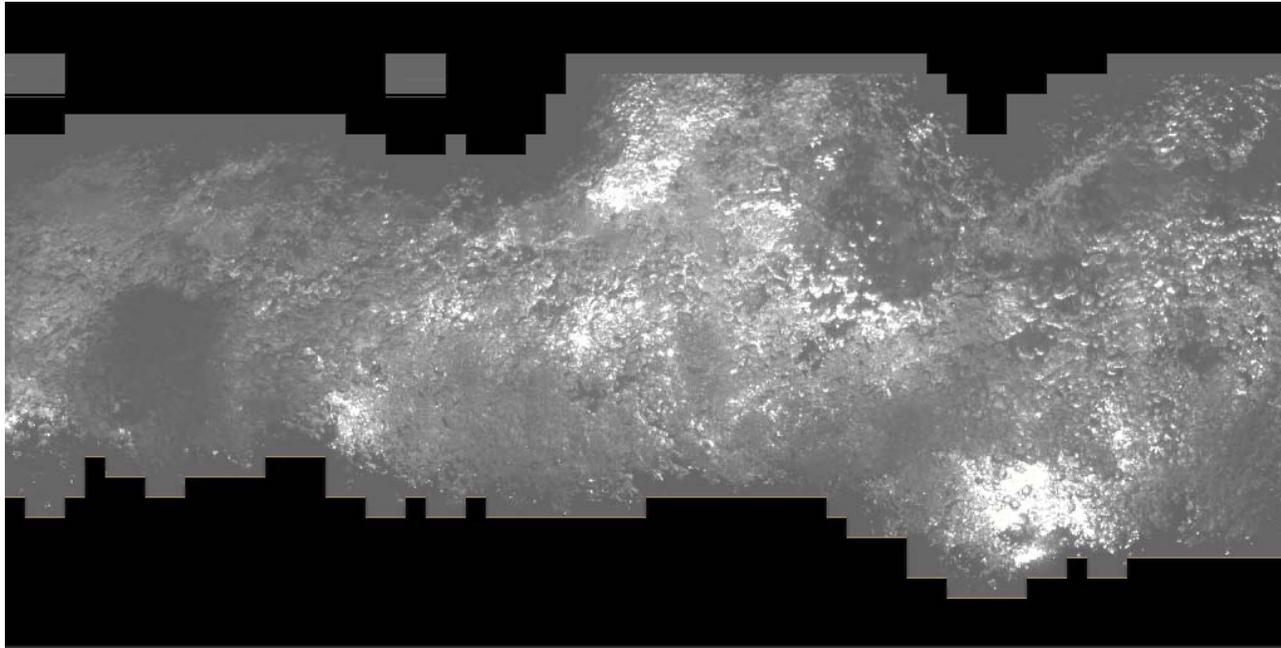
Turbulent pipe flow

$Re = 5300, 100 \times 85$ vectors

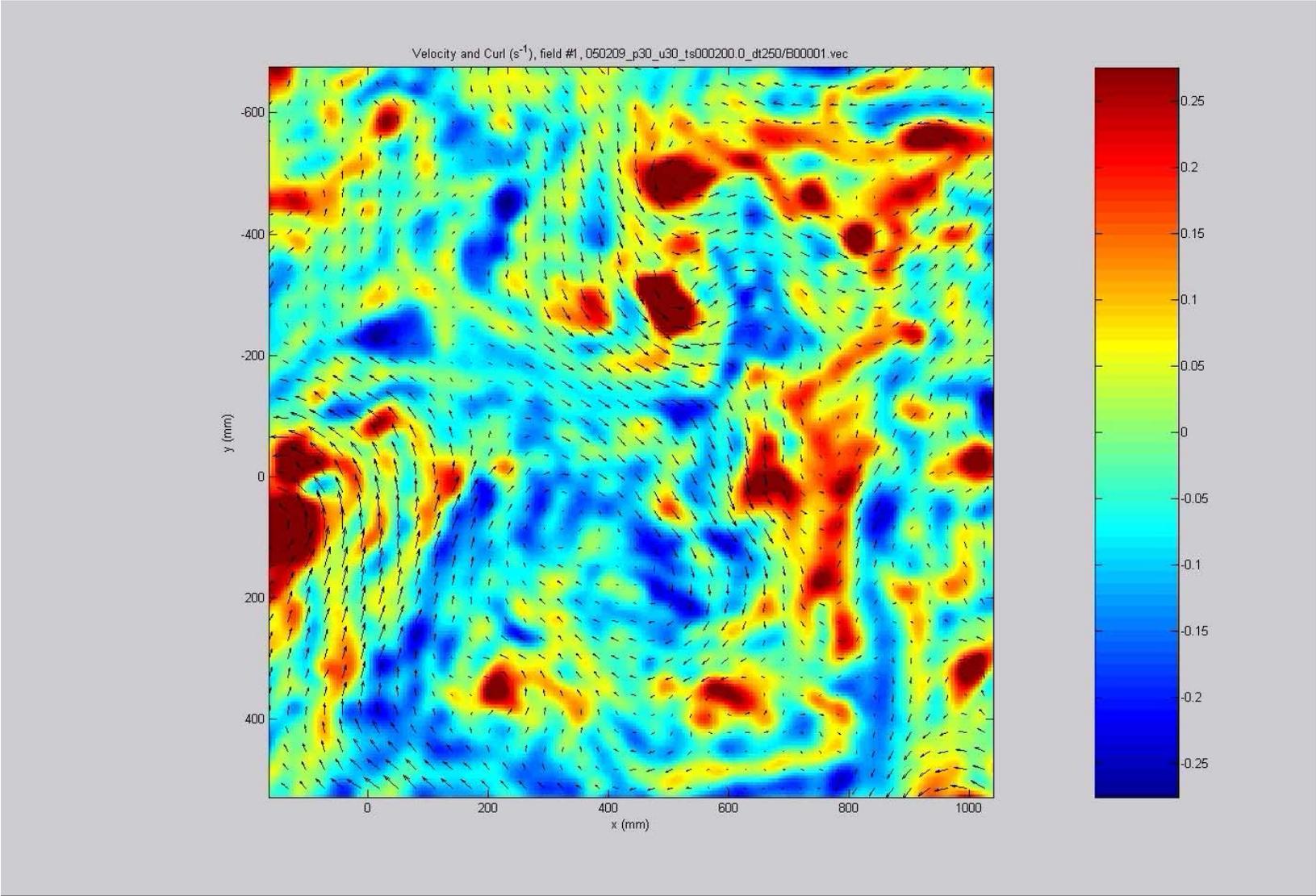


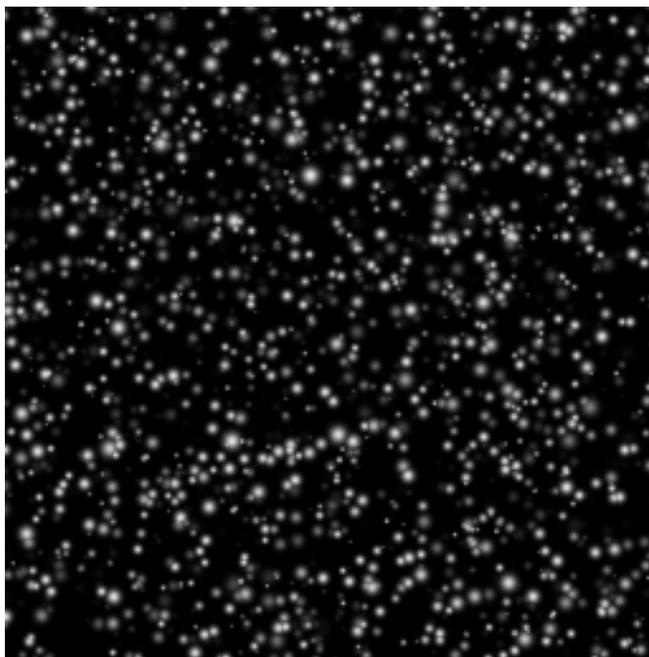
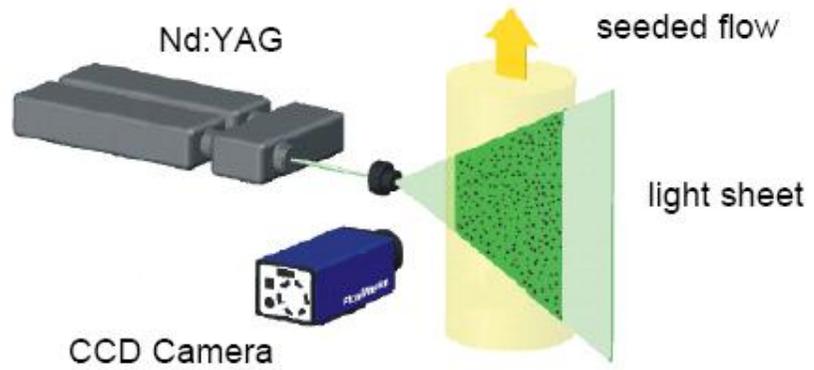






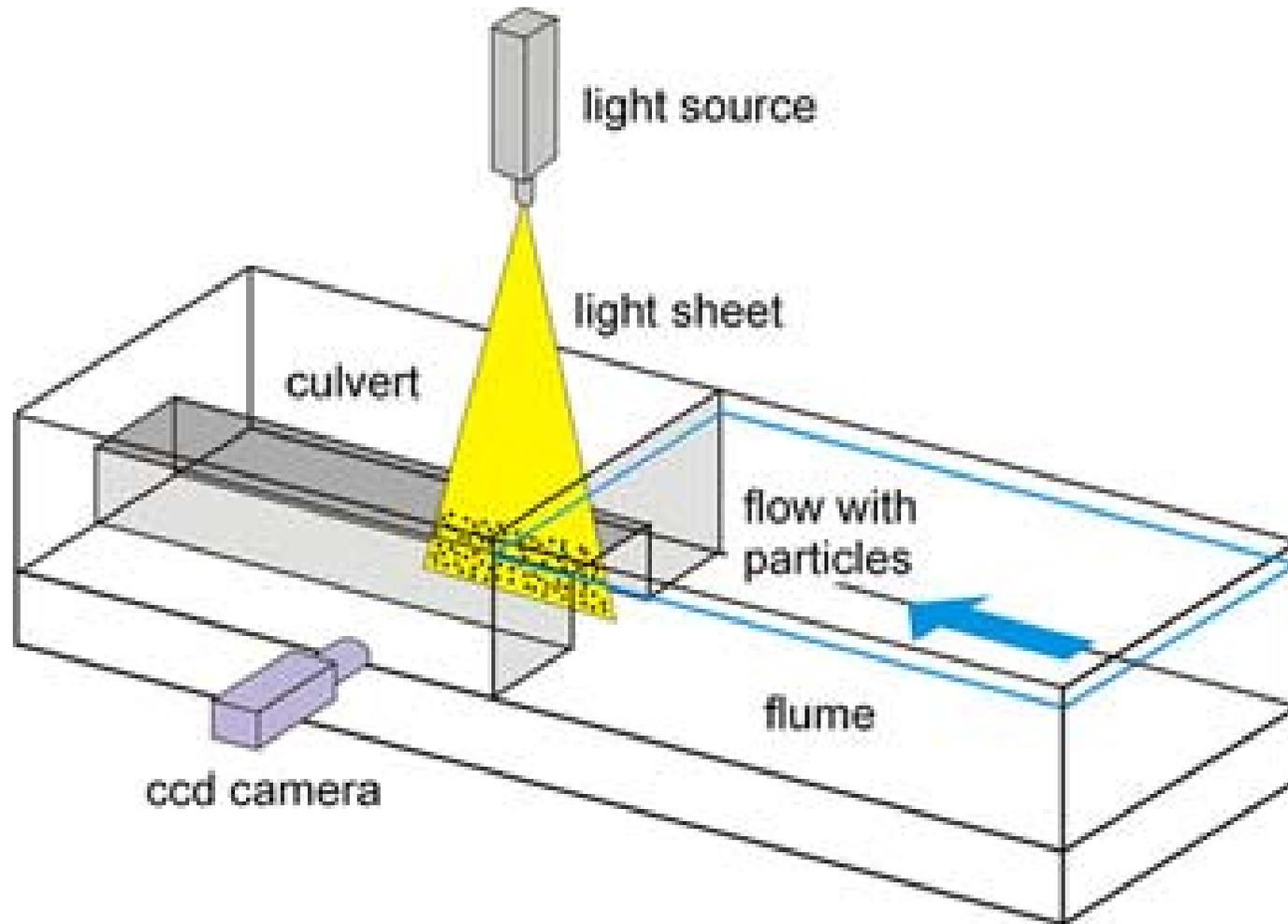
Turbulence en rotation
Collaboration FAST – Coriolis (Grenoble) - 2005

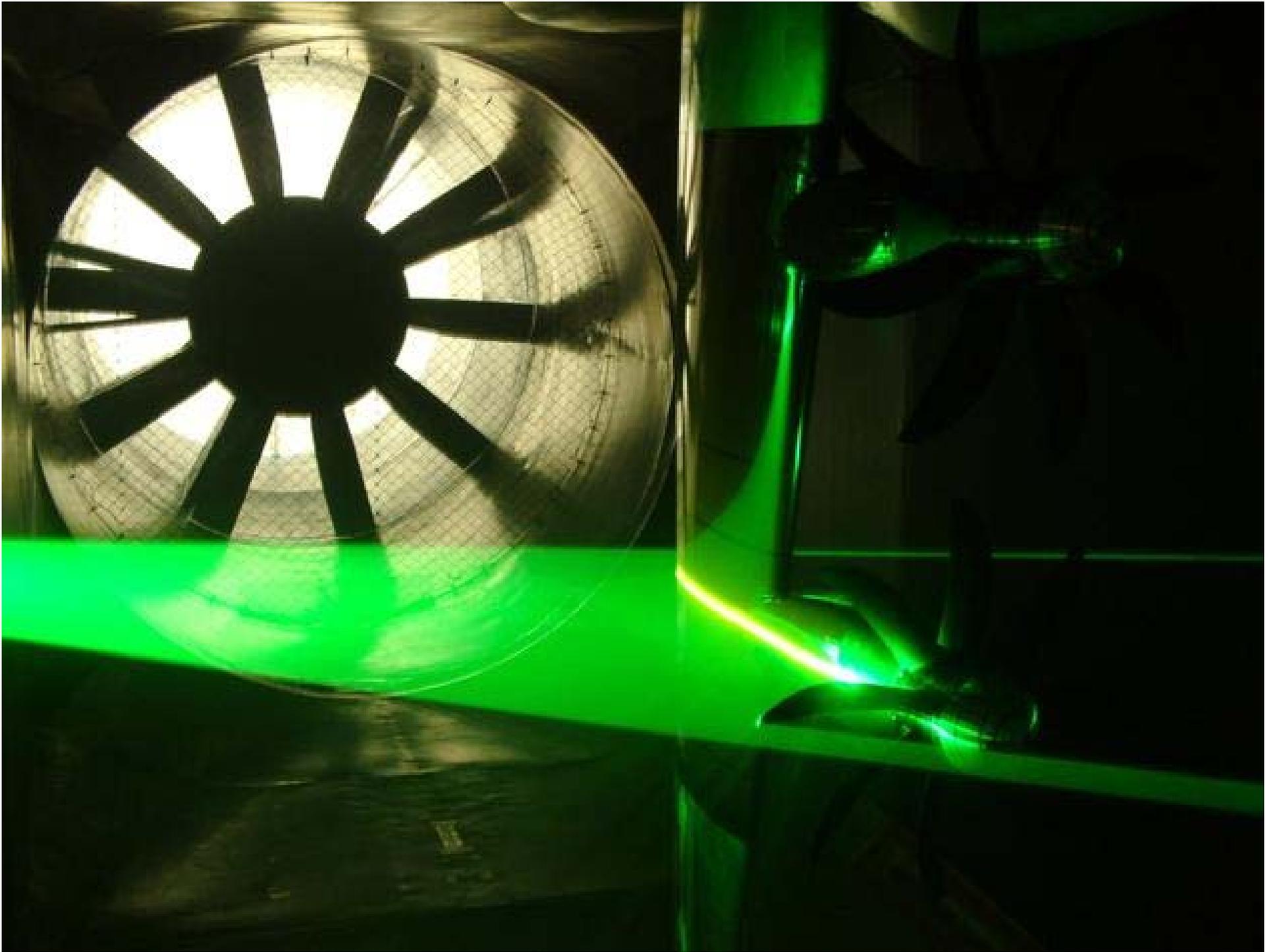


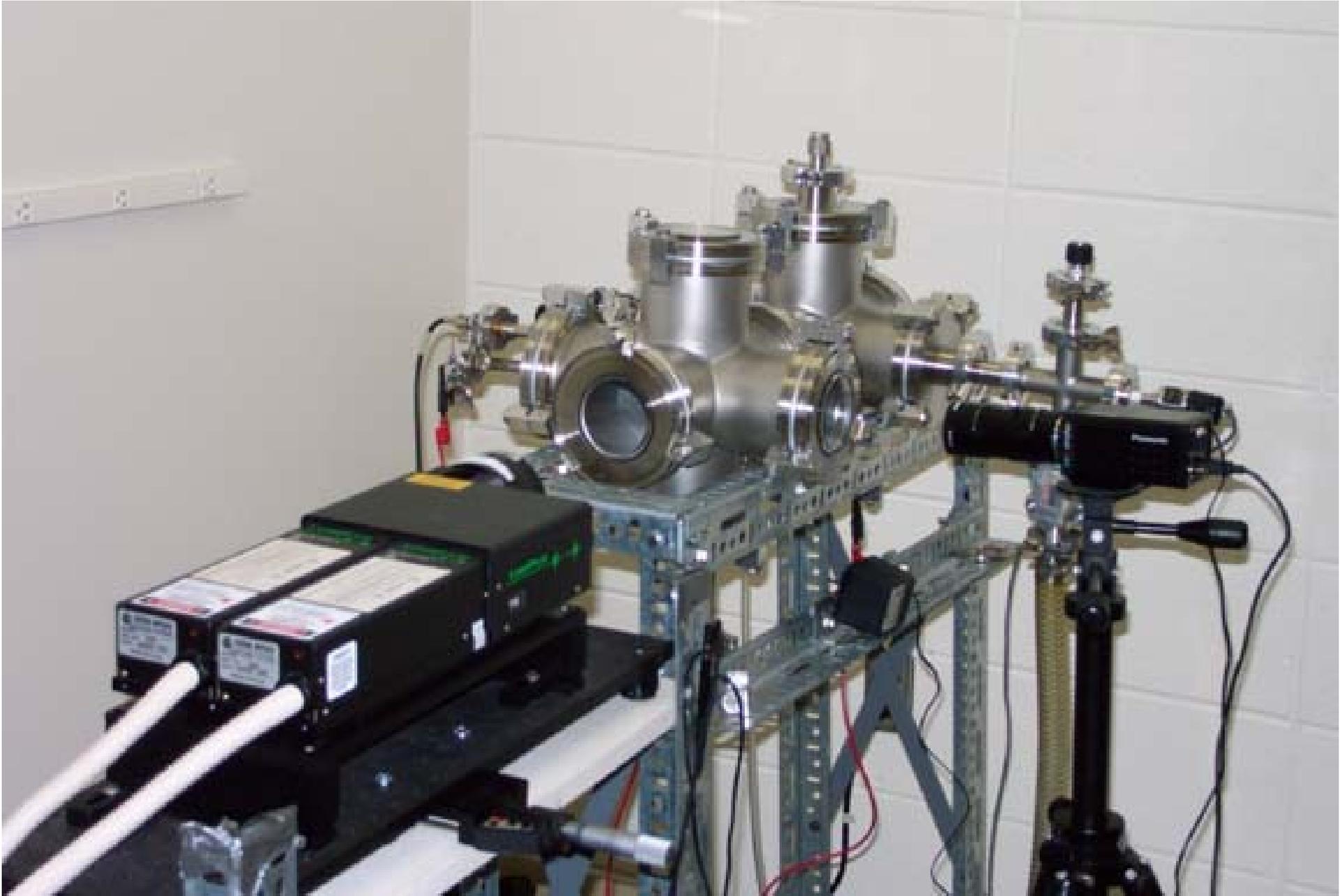


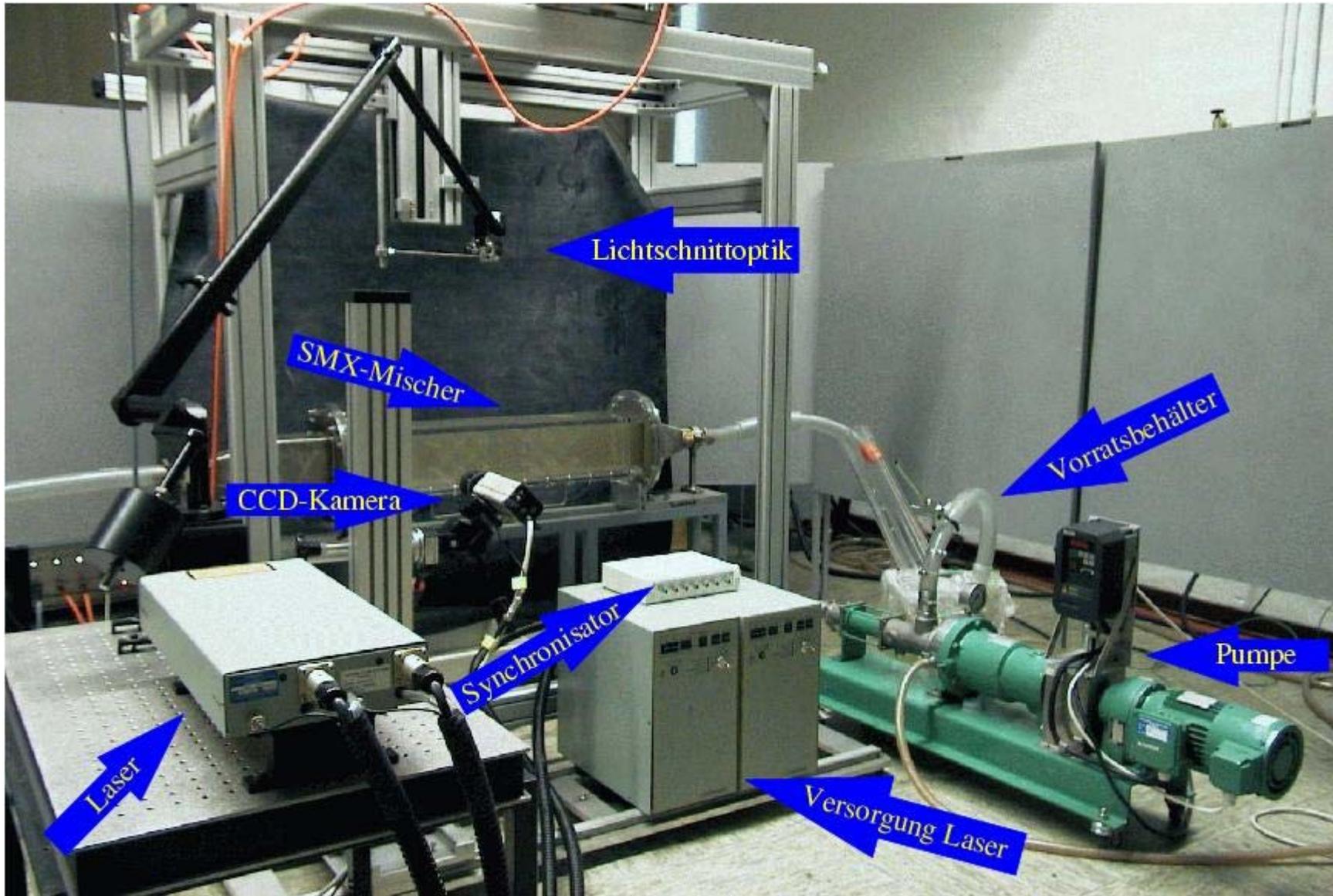
(d'après doc. LaVision)

Configuration optique



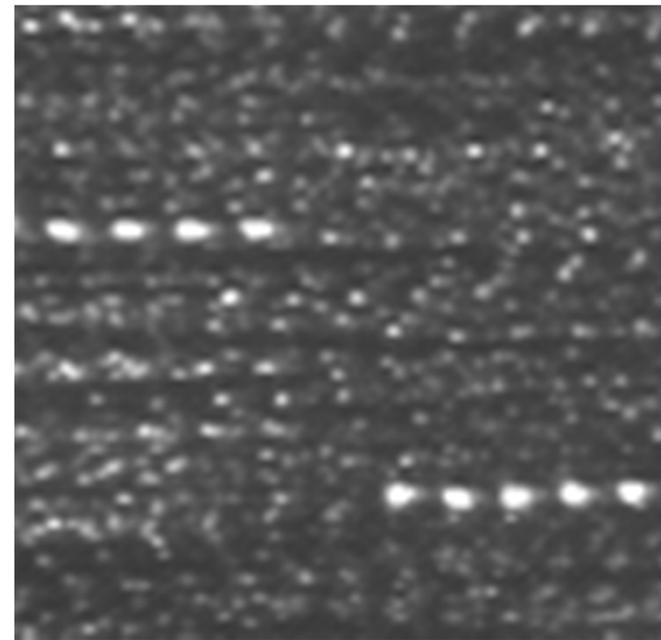
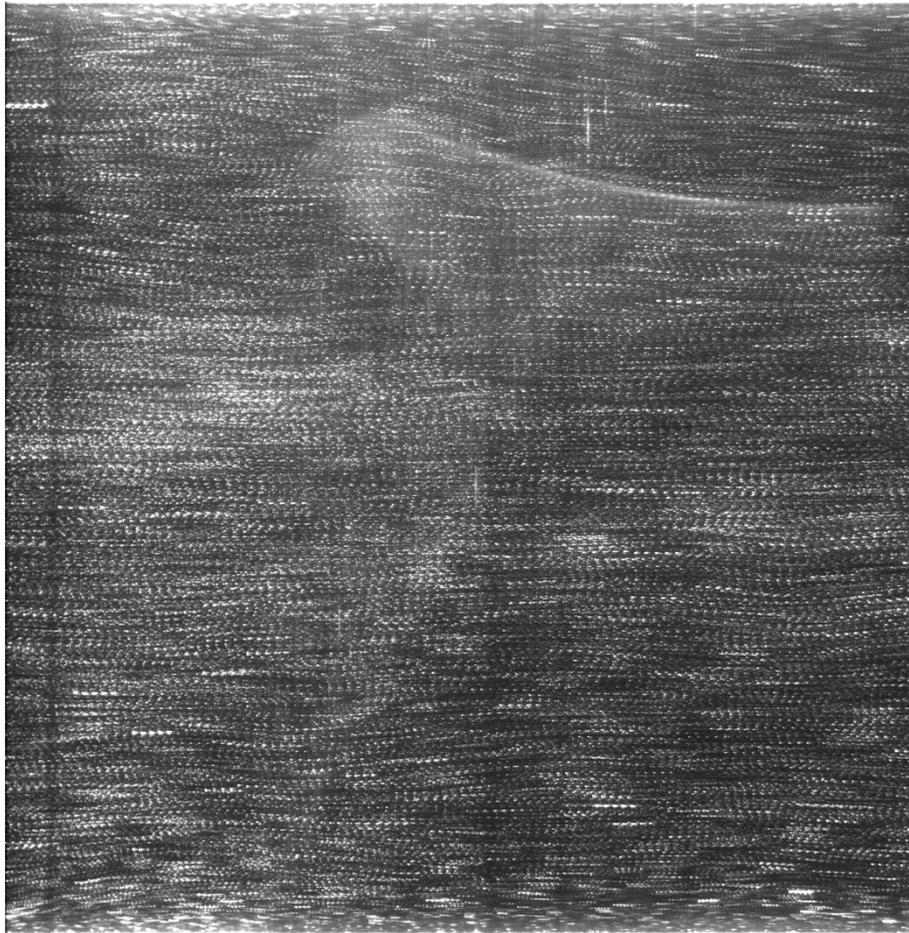


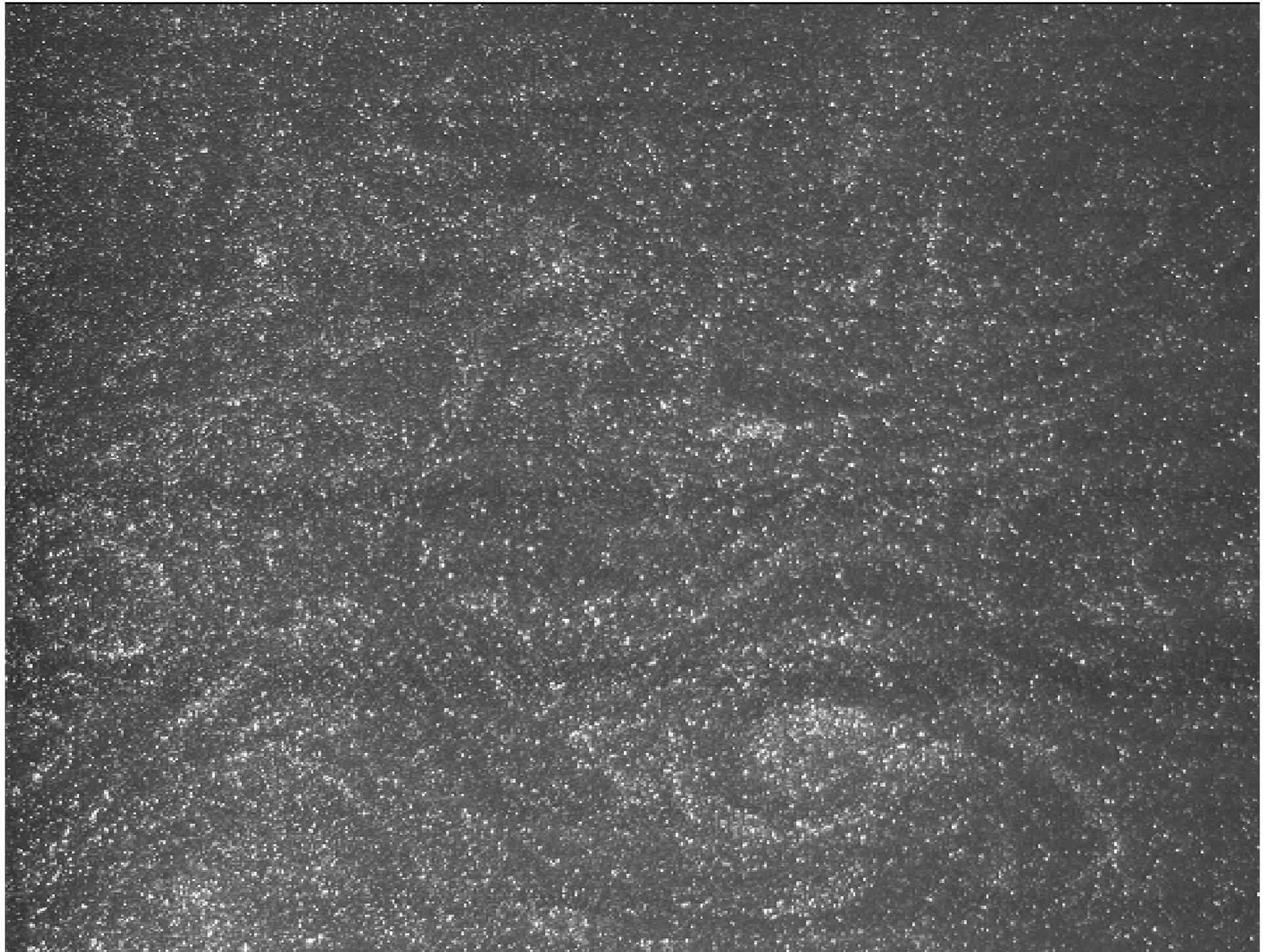


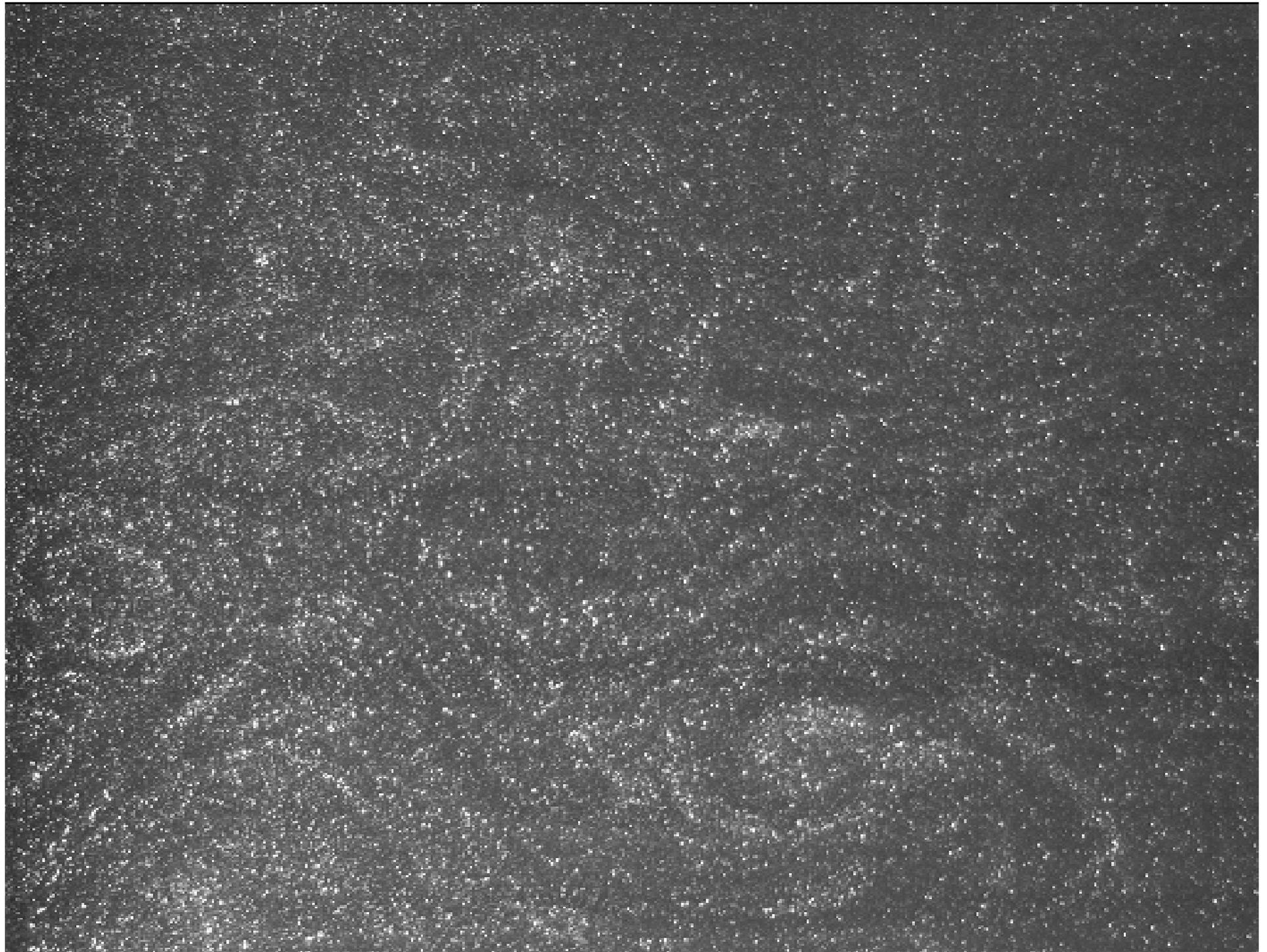


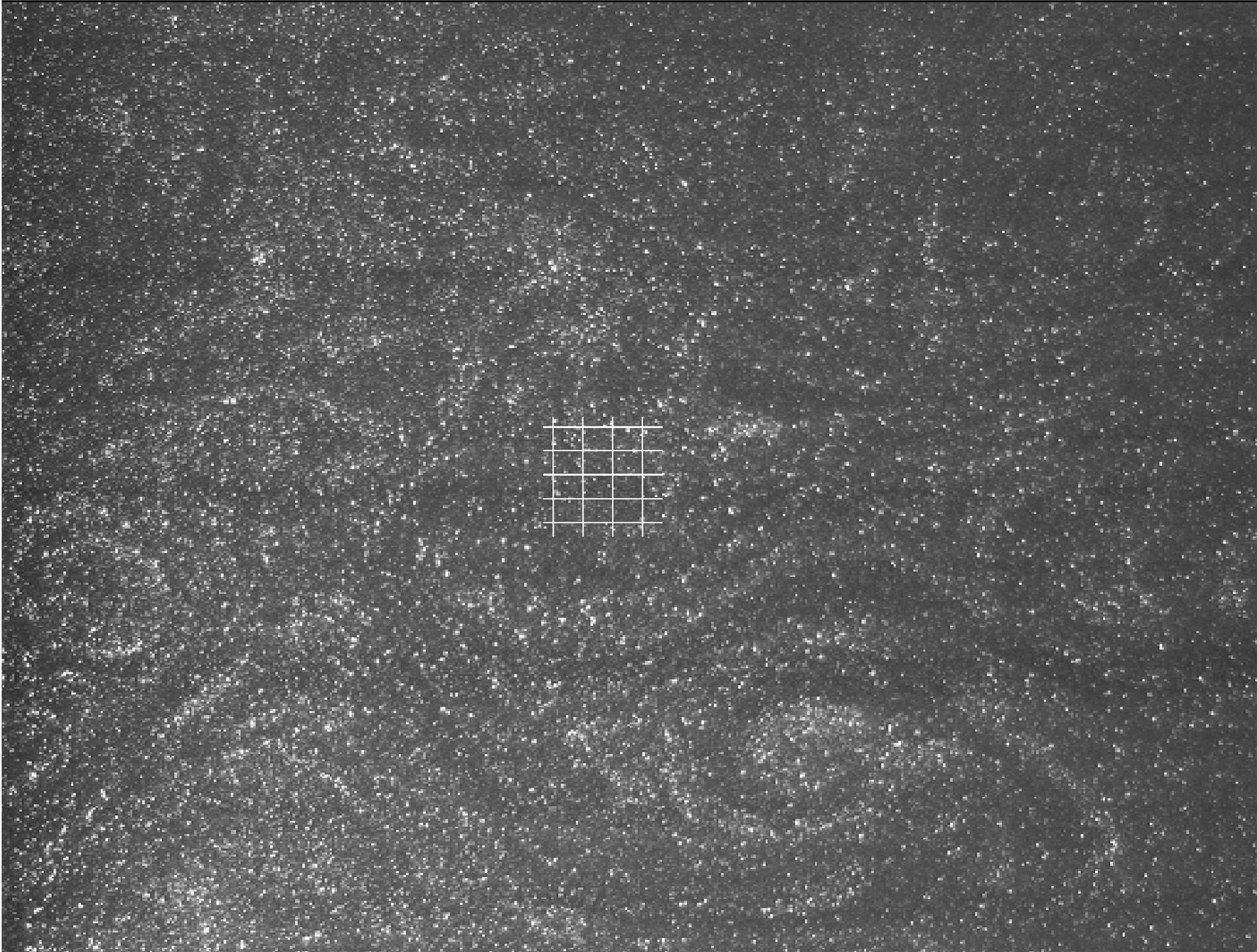
<http://www2.hsu-hh.de/pfs/pust/piv.jpg>

Multiple-exposure PIV image (obsolete)

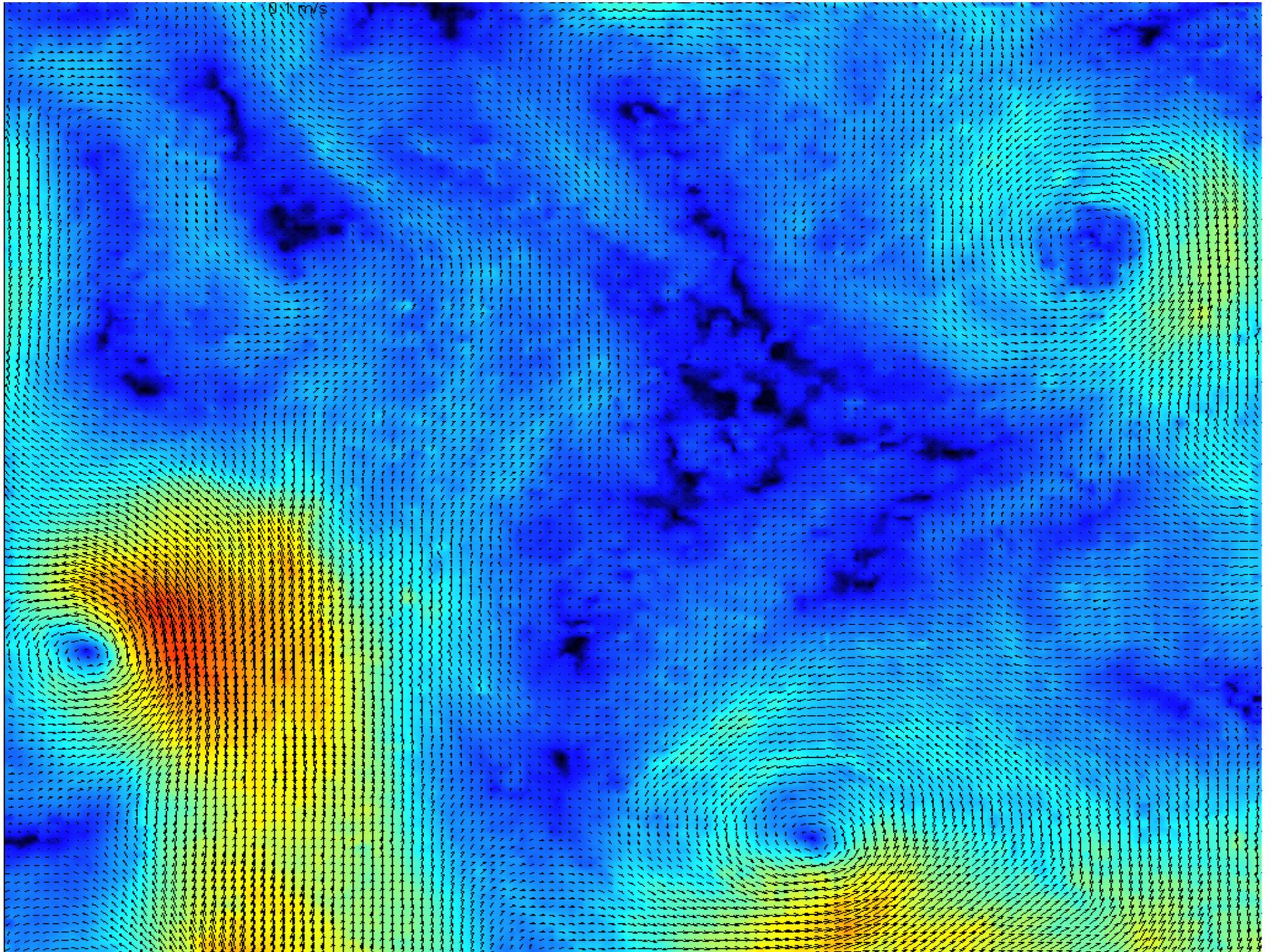


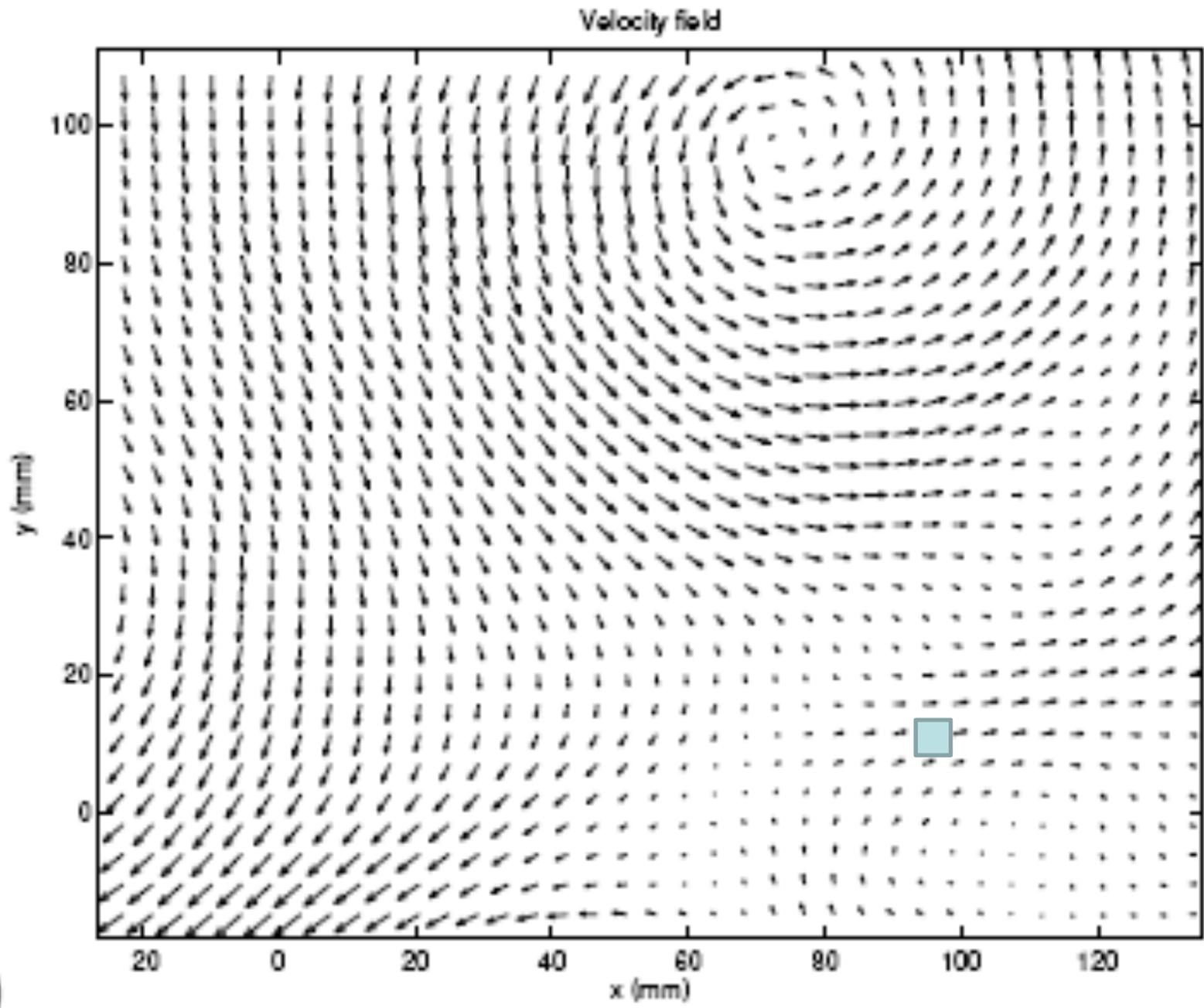


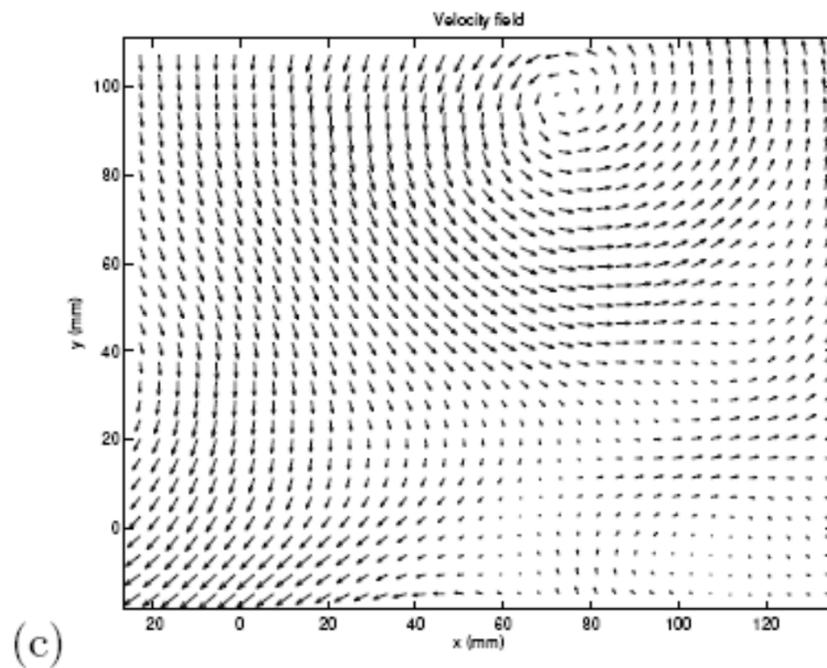
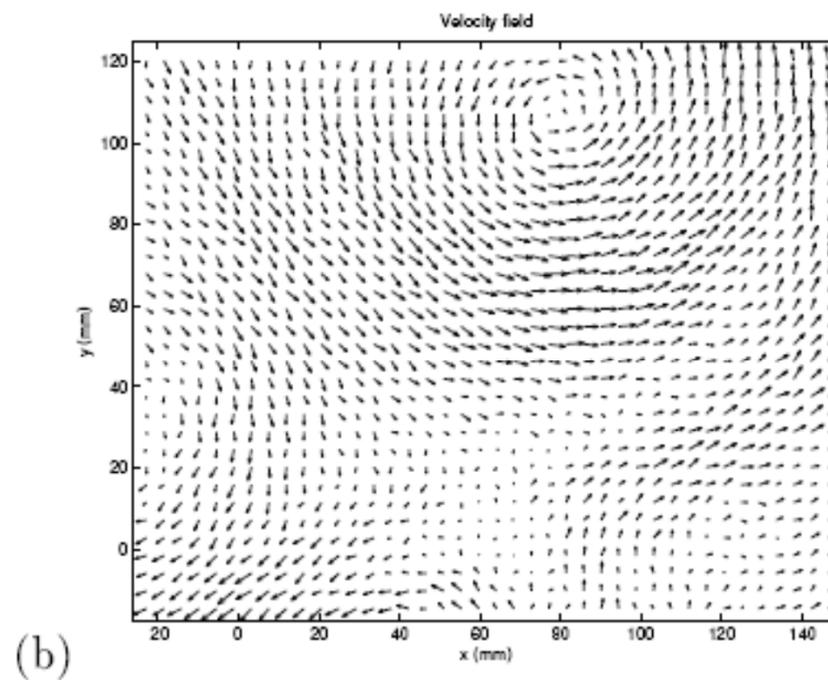
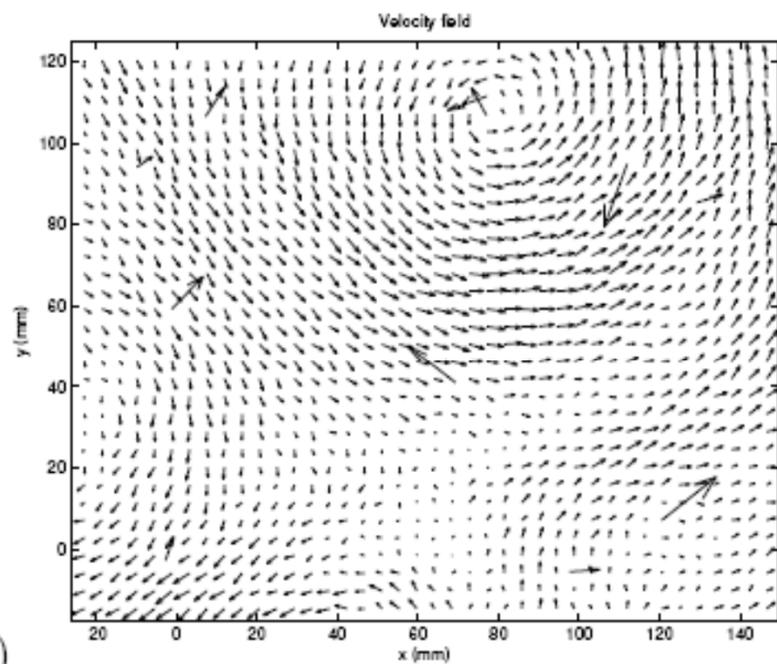




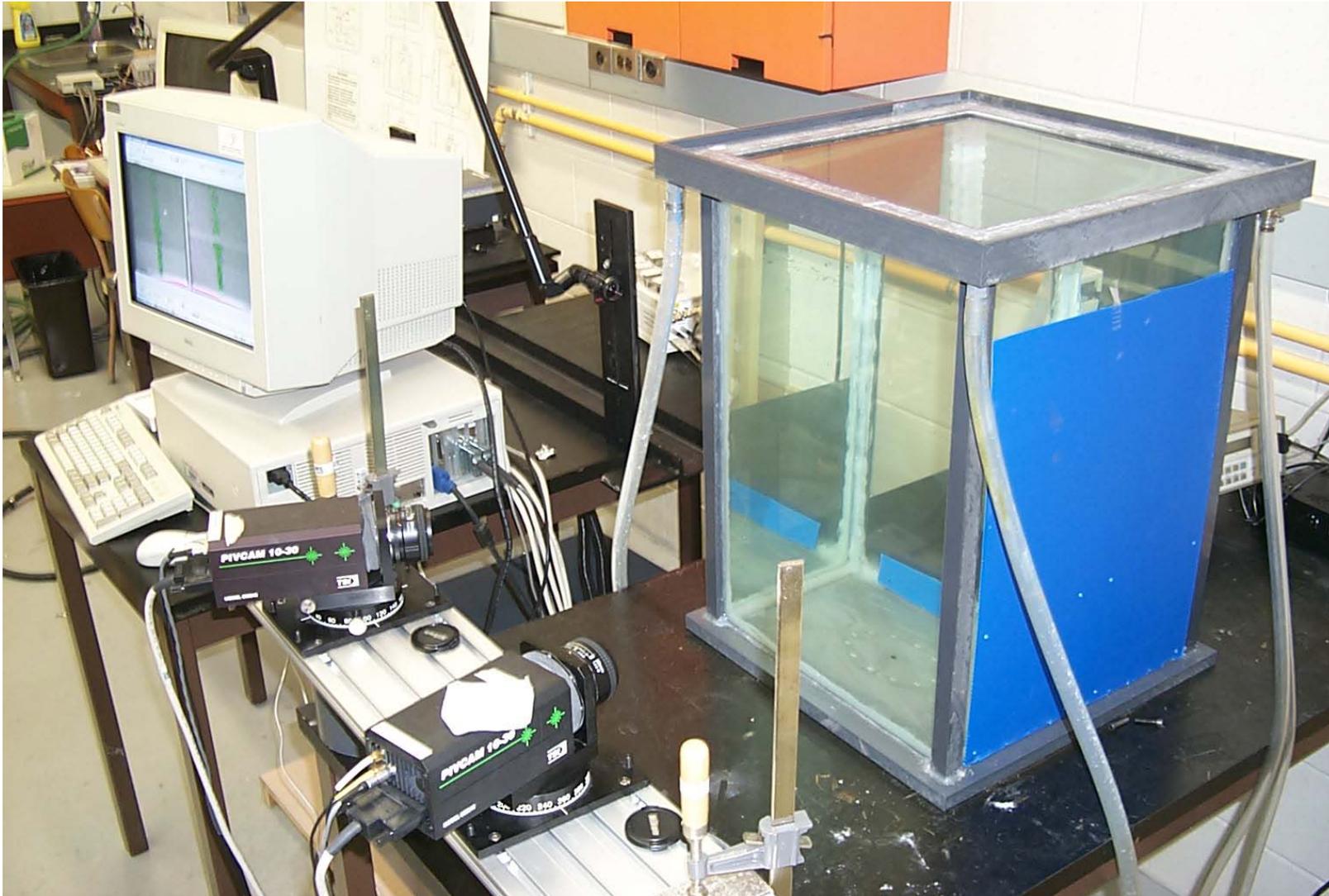
0.1775



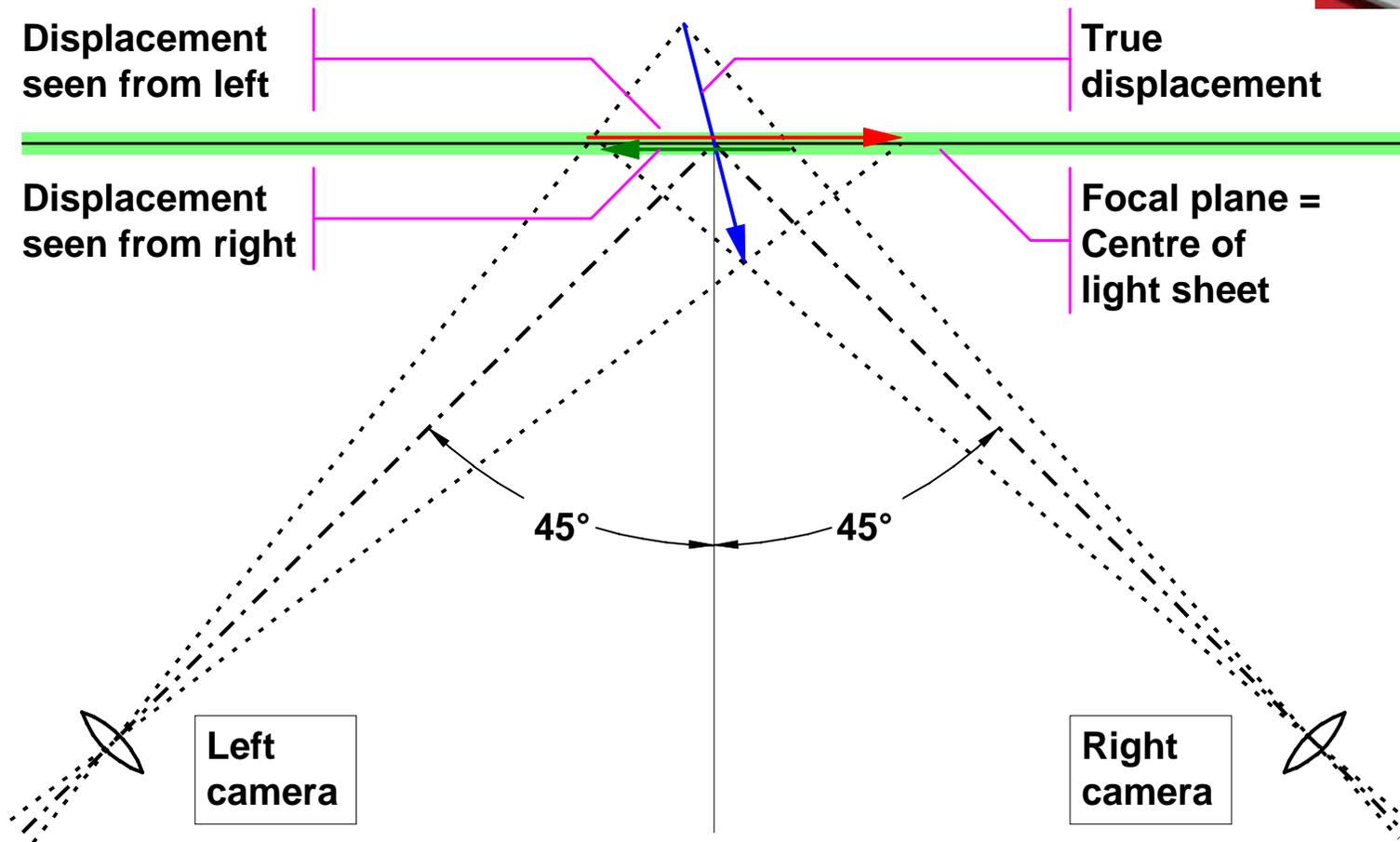




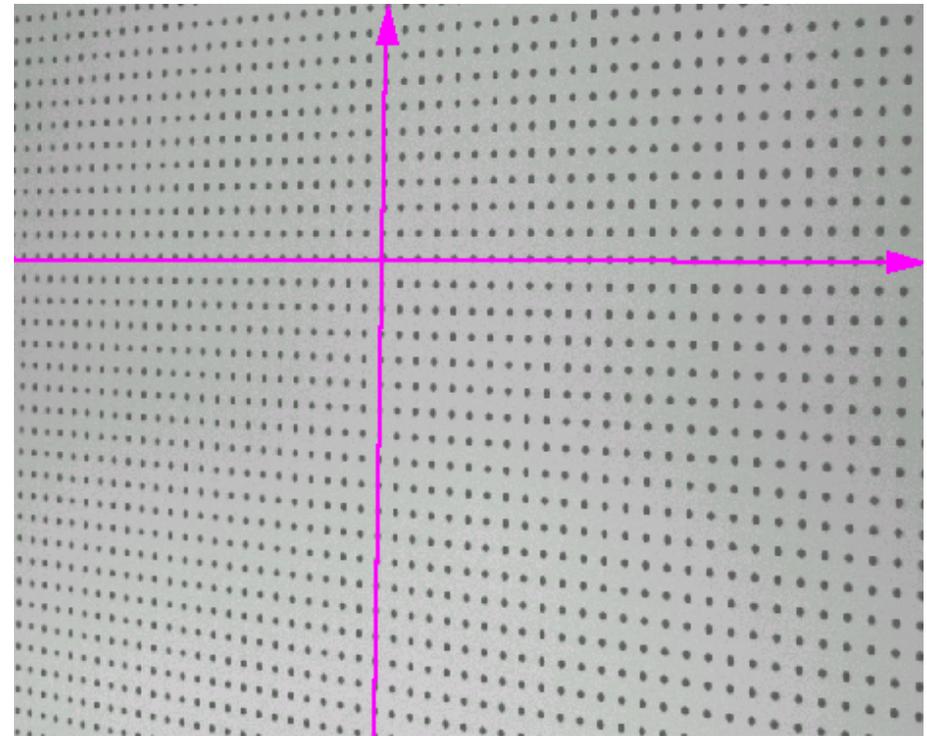
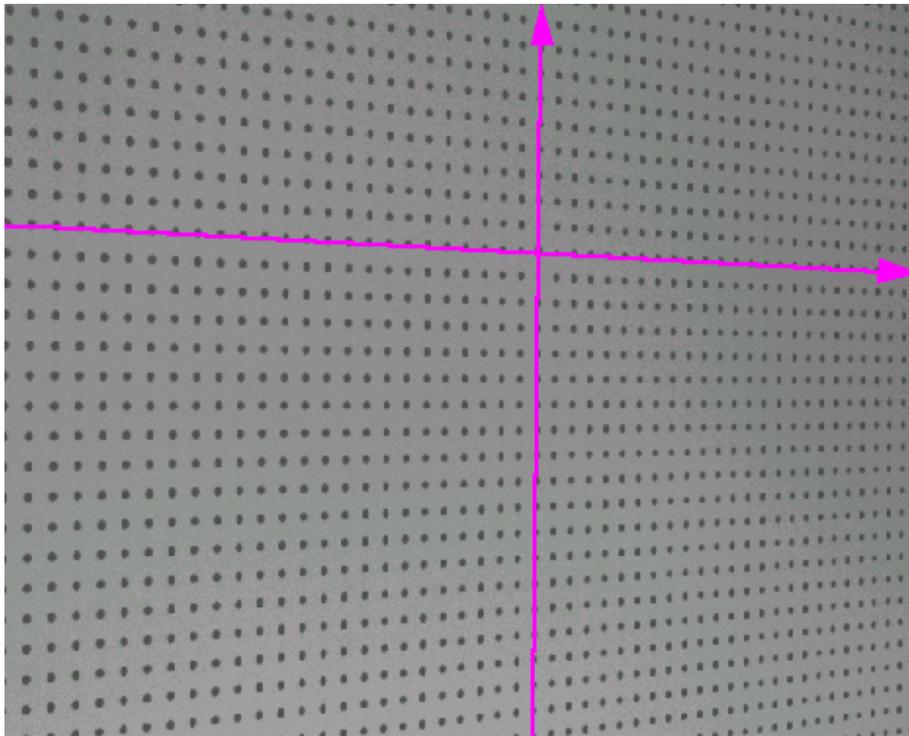
PIV stéréoscopique (3C2D)



PIV stéréoscopique (3C2D)

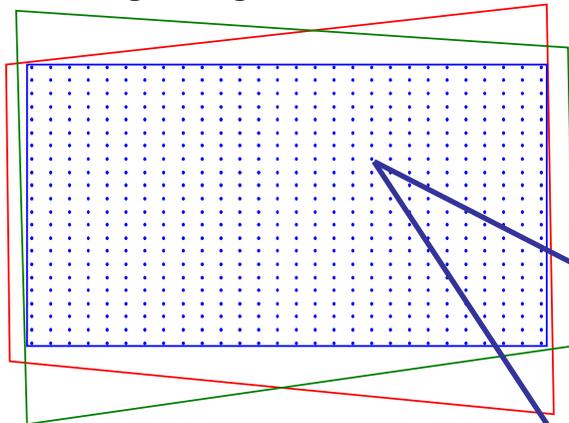


Camera calibration

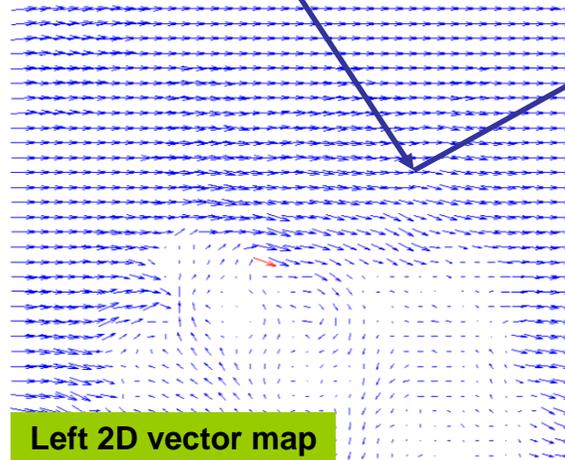
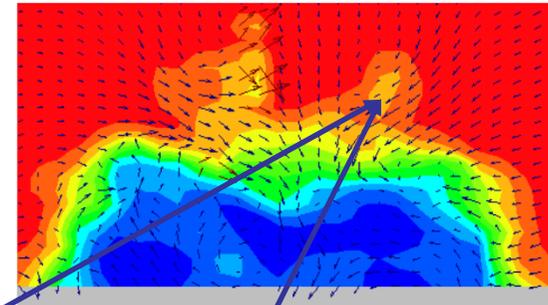


3D reconstruction

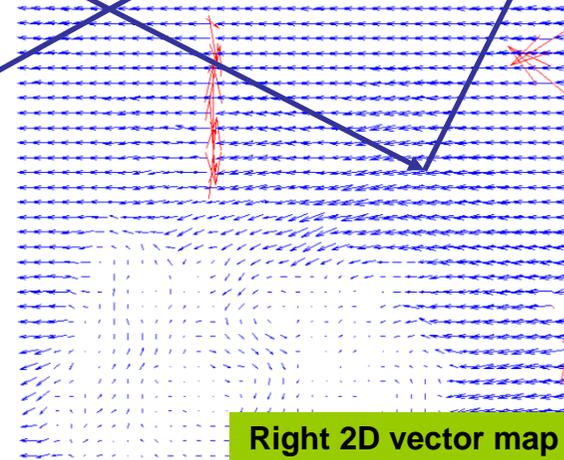
Overlap area with
interrogation grid



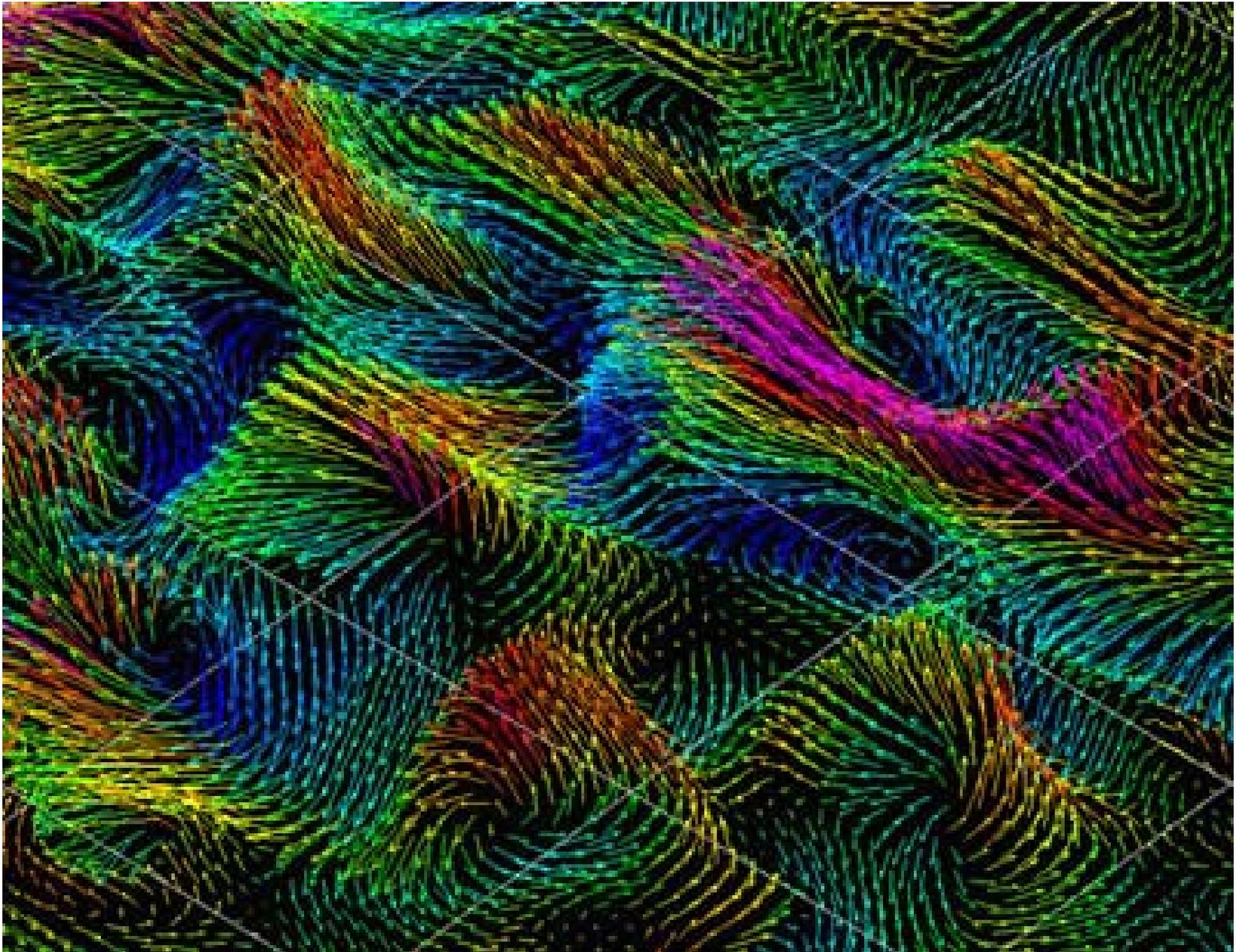
Resulting 3D vector map



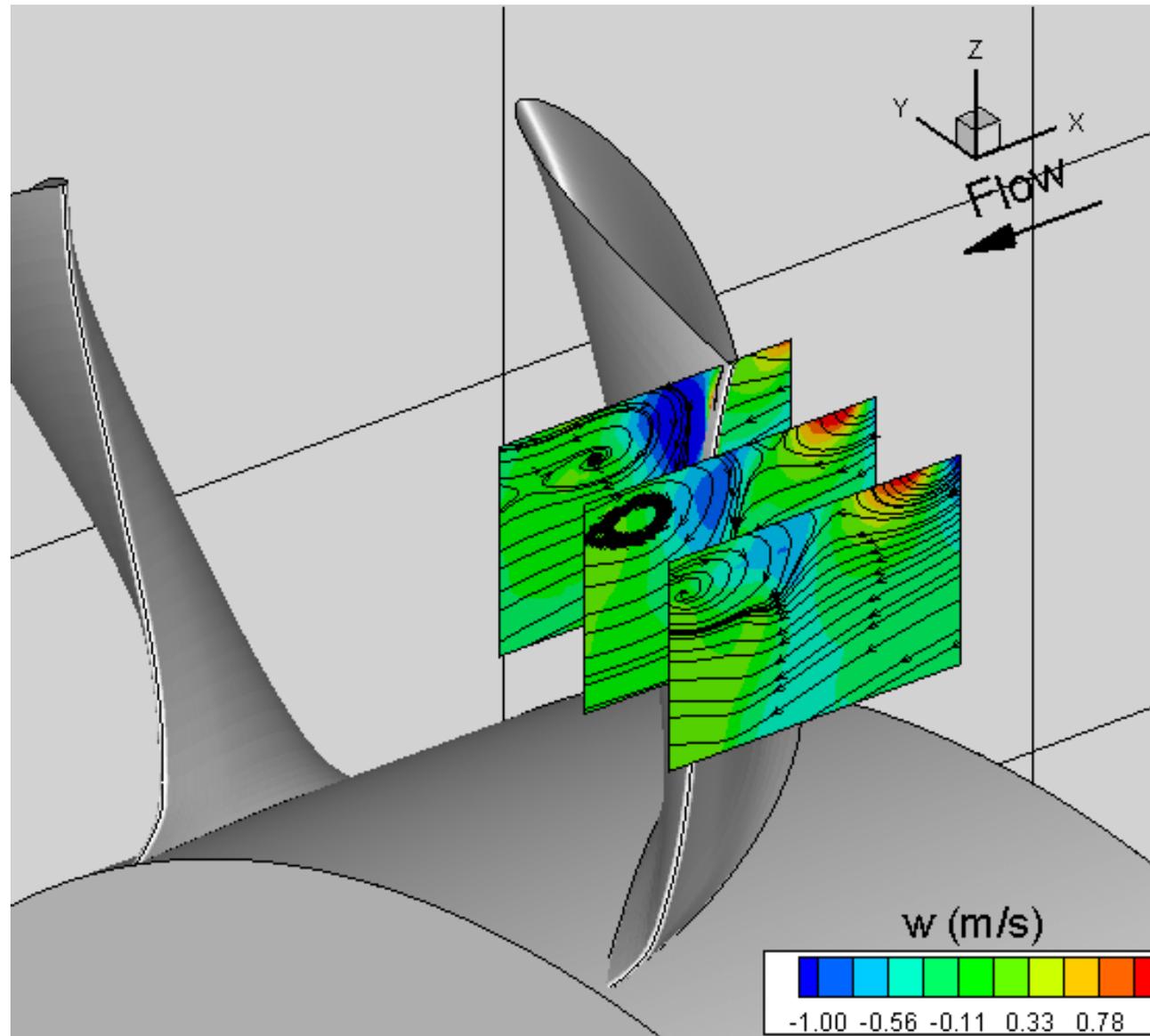
Left 2D vector map



Right 2D vector map



PIV multiplan (2C3D)



PIV tomographique (3C3D)

