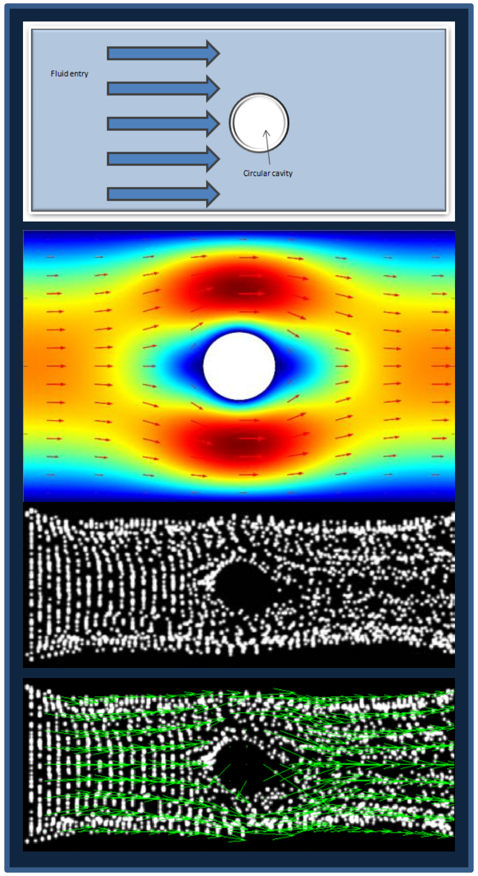

Particle Velocimetry Data from COMSOL Model of Micro-channels

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Particle Velocimetry Data from COMSOL Model of Micro-channels

1. Brief idea on μPIV
2. Evaluating μPIV Algorithms : Challenges
3. High quality images for μPIV algorithms : Using COMSOL
4. Results

Velocity Field estimation in Micro-channels

Application Examples

Near wall flow

- (a) Fluid-solid structure interaction
- (b) non-evasive shape determination
- (c) pressure distribution

Electrokinetic flow

- (a) Absolute fluid , absolute particle and relative motions
- (b) Particle migration issues

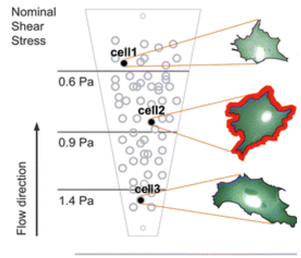
Biological flow

- (a) Velocity , pressure in living organisms (in vivo)
- (b) Handling , screening of biological samples (in vitro)

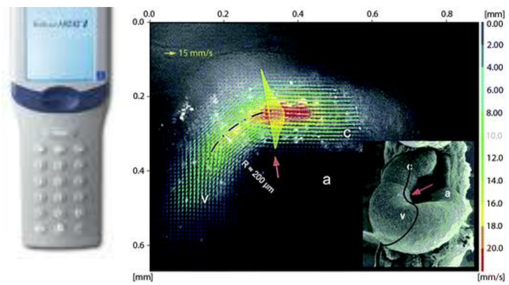
Mixing : Diffusion mixing in microfluidic devices due to laminar flow – impractical time/distance

-Flow details and fluid fields of active and passive n

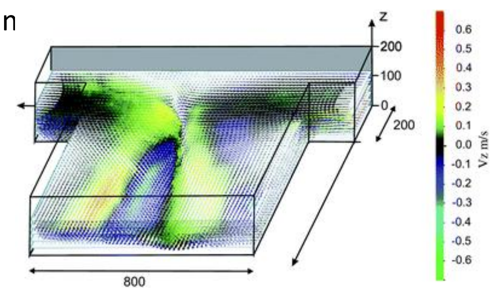
Thermometry : Analysis of Brownian motion of tracers



Lab-on-a-chip,2009



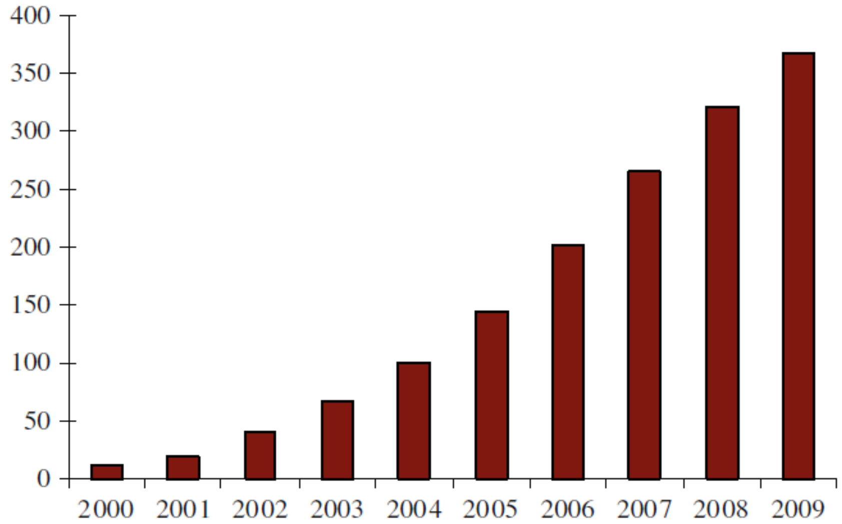
Exp. Fluids, 2007



Exp. Fluids, 2006

Accurate velocity measurement in microchannels

Flow measurement in micro-channels : Particle Image Velocimetry



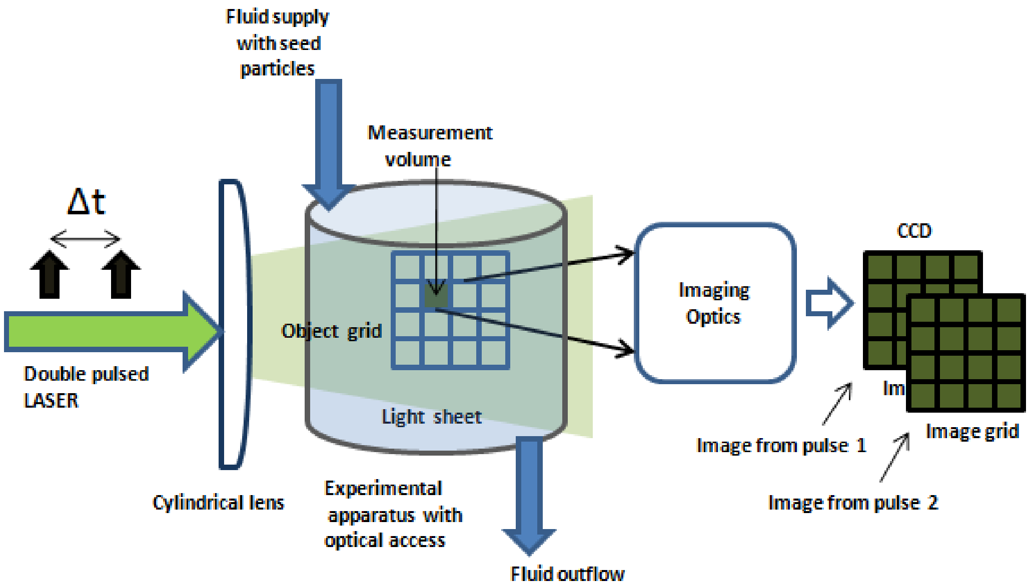
Source :

Advances and applications on microfluidic velocimetry techniques
Stuart J. Williams , Choongbae Park ,Steven T. Wereley
Microfluid Nanofluid (2010) 8:709–726

Micron-Resolution Velocimetry Techniques
C. D. Meinhart, S. T. Wereley, and J. G. Santiago
Developments in Laser Techniques and Applications
to Fluid Mechanics,Springer-Verlag, Berlin, 1998.

Technique	Author	Flow Tracer	Spatial Resolution (μm)	Observation
LDA	Tieu et al. (1995)	______	$5 \times 5 \times 10$	4 – 8 Fringes limits velocity resolution
Optical Doppler Tomography (ODT)	Chen et al. (1997)	1.7 μm Polystyrene Beads	5×15	Can image through highly scattering media
Optical Flow using Video Microscopy	Hitt et al. (1996)	5 μm Blood Cells	$20 \times 20 \times 20$	In vivo study of blood flow
Optical Flow using X-ray imaging	Lanzillotto et al. (1996)	1 – 20 μm Emulsion Droplets	~ 20 - 40	Can image without optical access
Uncaged-fluorescent dyes	Paul et al. (1997)	Molecular Dye	$100 \times 20 \times 20$	Resolution limited by molecular diffusion
Particle Streak Velocimetry	Brody et al. (1996)	0.9 μm Polystyrene Beads	~ 10	Particle Streak Velocimetry
Particle Image Velocimetry (PIV)	Urushihara et al. (1993)	1 μm oil droplets	$280 \times 280 \times 200$	Turbulent flows
Super-resolution PIV	Keane et al. (1995)	1 μm oil droplets	$50 \times 50 \times 200$	Particle Tracking Velocimetry
Micro PIV	Santiago et al. (1998a)	300 nm polystyrene particles	$6.9 \times 6.9 \times 1.5$	Hele-Shaw Flow
Micro PIV	Santiago et al. (1998b)	300 nm polystyrene particles	6.9 x 6.9 x 1.5	Silicon Microchannel Flow
Micro PIV	Meinhart et al. (1999)	200 nm polystyrene particles	$5.0 \times 1.3 \times 2.8$	Microchannel Flow

Micro Particle Image Velocimetry



1. Micro-PIV is PIV in micron resolution.

2. Conventional microscopy and digital imaging methods.

3. Tracer particles 200nm-2um.

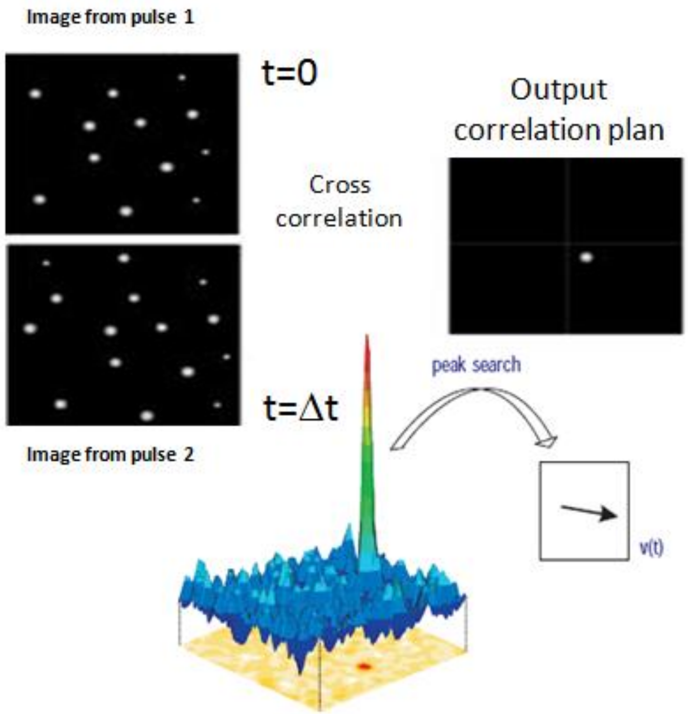
4. Volume illumination, pulsed , synchronized light source.

5. Depth of correlation strongly dependant on the numerical aperture and particle size.

6. Position of cross-correlation peak gives mean displacement of the region-of-interest.

7. Spatially uniform seeding density preferred.

8. Uniformly gridded interrogation regions : uniform sampling of low-pass filtered spatial velocity field components.



Challenges for μPIV

1. Size of particles very important.

	Follow the flow	Light scattering
Small particles	Good	Bad
Large particles	Bad	Good

2. **Seeding density** problem [Dense field and good tracking vs Noise and particle agglomeration]

3. **High speed imaging** : Prevent motion blur of particle images and decorrelation of signal due to velocity gradients.

4. **Spurious vector correction** in post processing.

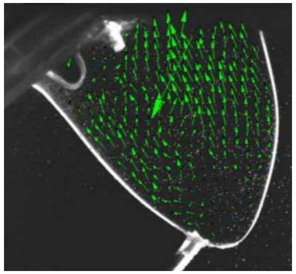
   Low particles density

   Inhomogeneous particles seeding

   Particles within a vortex

   Low S/N

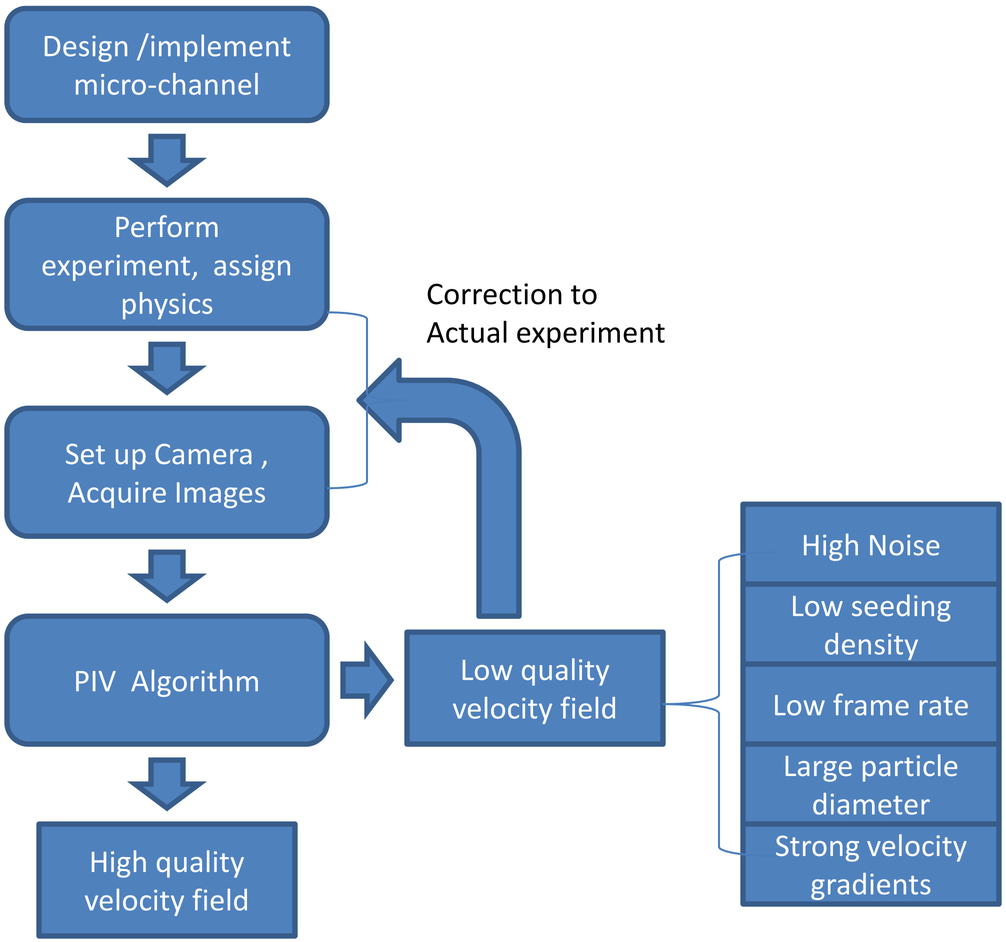
   3D movement of the particles



5. Mostly **steady state flows or periodic flows** work best

Would the acquired images work ?
Would the algorithm work ?
How good will the algorithm work ?

High quality PIV images for algorithm

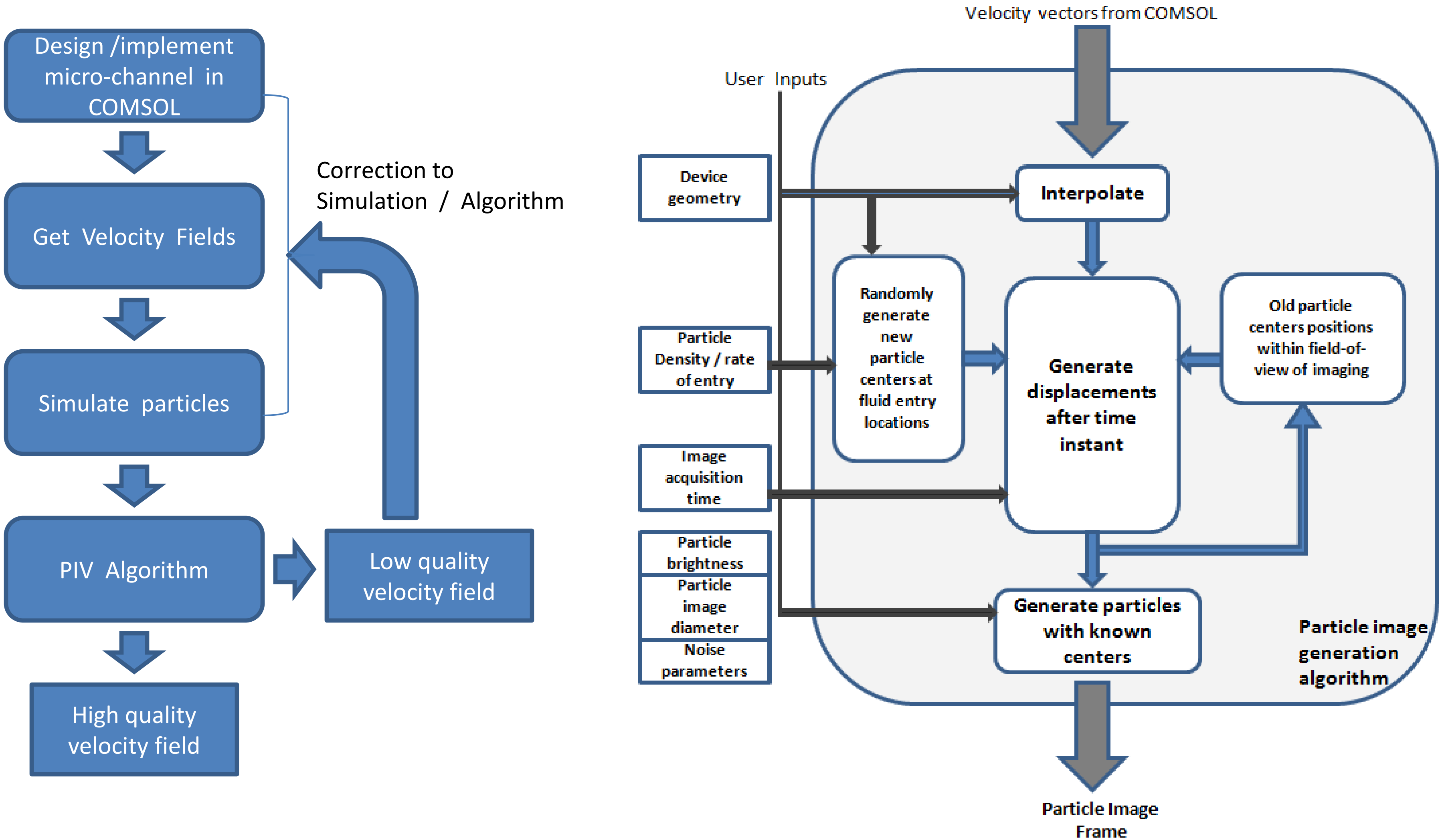


1. More time is spent in acquiring data than in the actual algorithm processing
2. Some parameters e.g. Tracer particle size are more difficult to change during an experiment. (more so while using PDMS channels)
3. In some cases, the algorithm may not be optimal for the channel or can be made optimal if we know how the particles are going to behave beforehand

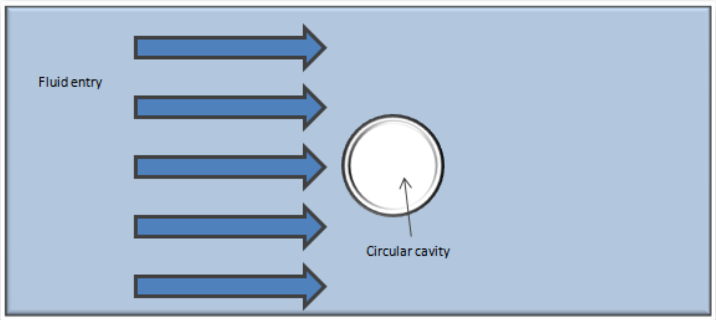
CAN WE SIMULATE THE IMAGES BASED ON REAL PHYSICS ?

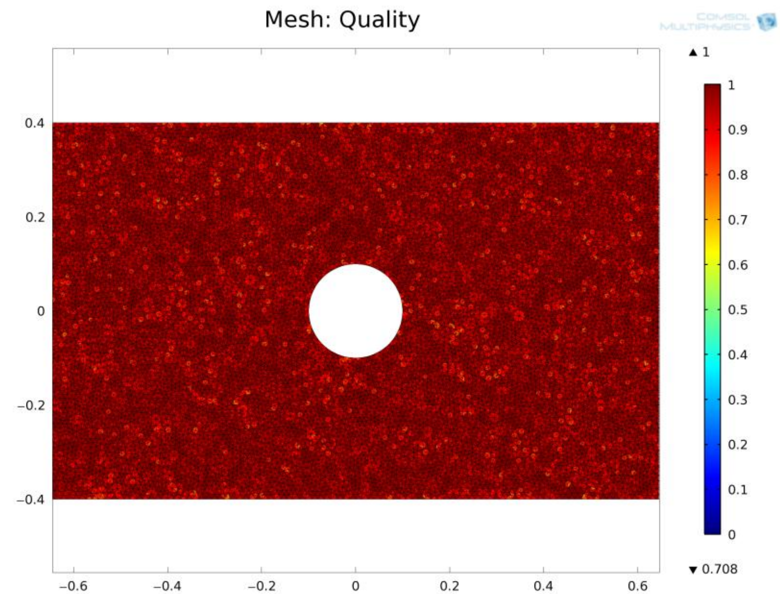
YES , BUT ……
Closed form solutions from physics for user defined microfluidic experiment is **not** available **ALMOST ALWAYS**

Using COMSOL to generate images



Example : Using COMSOL to generate images





Solutions in polar coordinates

$$V_r = \frac{\partial \phi}{\partial r} = V_c\left(1 - \frac{R^2}{r^2}\right)\cos\theta \qquad V_\theta = \frac{1}{r}\frac{\partial \phi}{\partial \theta} = -V_c\left(1 + \frac{R^2}{r^2}\right)\sin\theta$$

ϕ is velocity potential

Equation

Equation form:

Study controlled

Show equation assuming:

Study 1, Stationary

$$\rho(\mathbf{u}\cdot\nabla)\mathbf{u} = \nabla\cdot\left[-p\mathbf{I} + \mu\left(\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right)\right] + \mathbf{F}$$

$$\rho\nabla\cdot\mathbf{u} = 0$$

Physical Model

Compressibility:

Incompressible flow

Turbulence model type:

None

Inlet

Equation

Show equation assuming:

Study 1, Stationary

$$p = p_0, \quad \left[\mu\left(\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right)\right]\mathbf{n} = 0$$

Boundary Condition

Boundary condition:

Pressure, no viscous stress

Pressure:

p_0 101310 Pa

Outlet

Equation

Show equation assuming:

Study 1, Stationary

$$p = p_0, \quad \left[\mu\left(\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right)\right]\mathbf{n} = 0$$

Boundary Condition

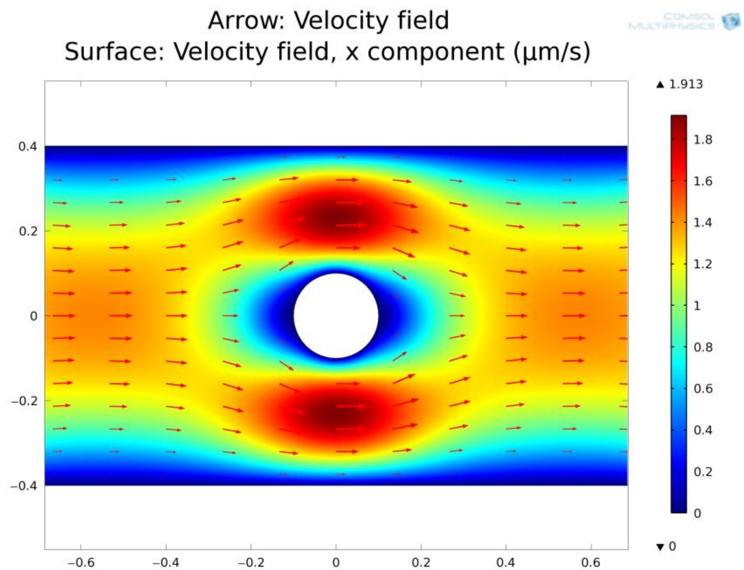
Boundary condition:

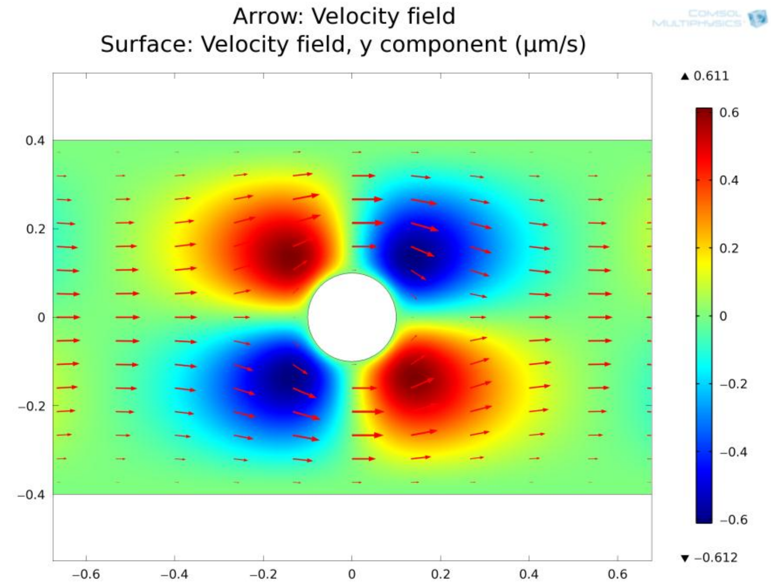
Pressure, no viscous stress

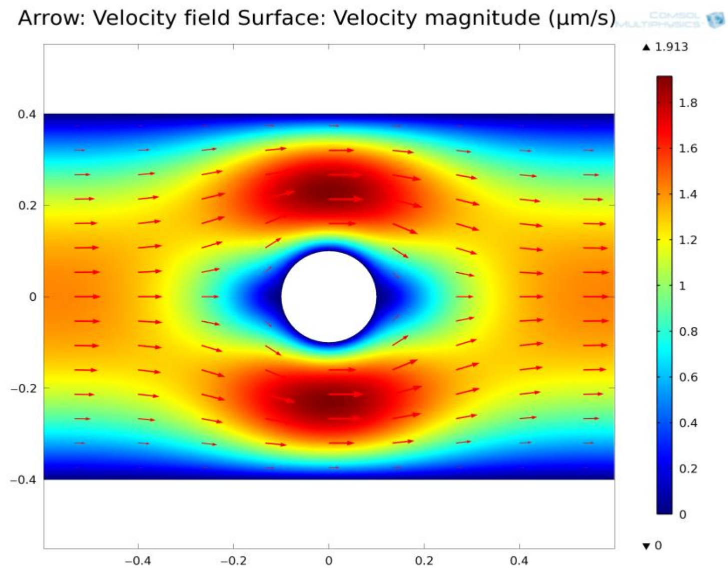
Pressure:

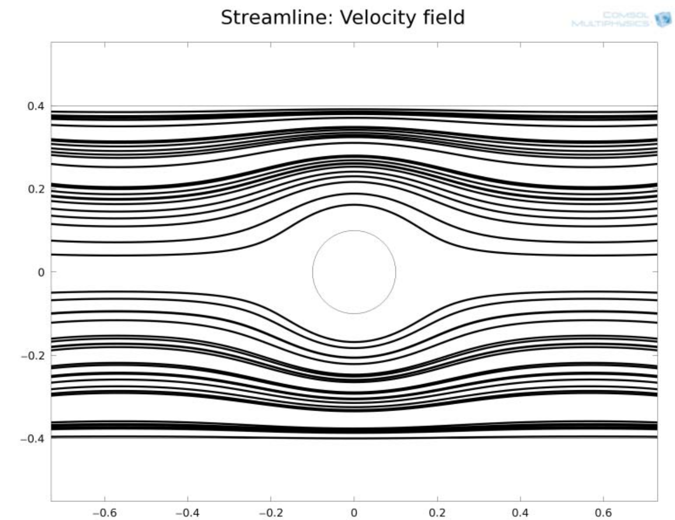
p_0 101300 Pa

Using COMSOL to generate images

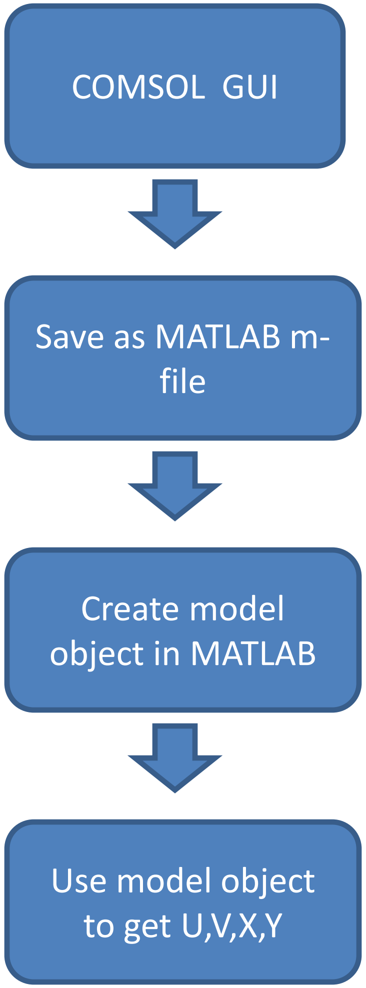






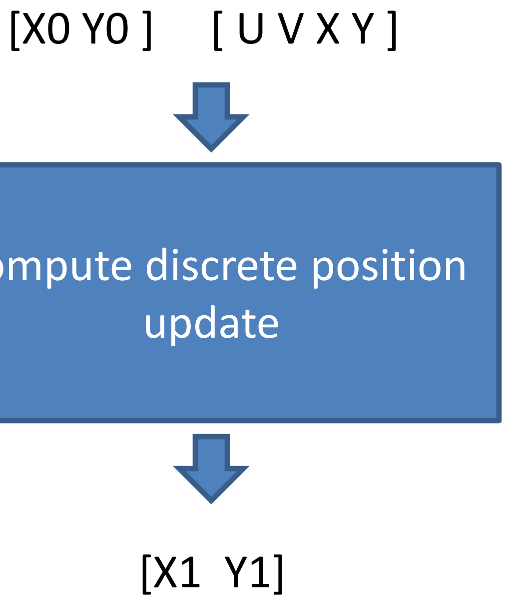


Using COMSOL to generate images



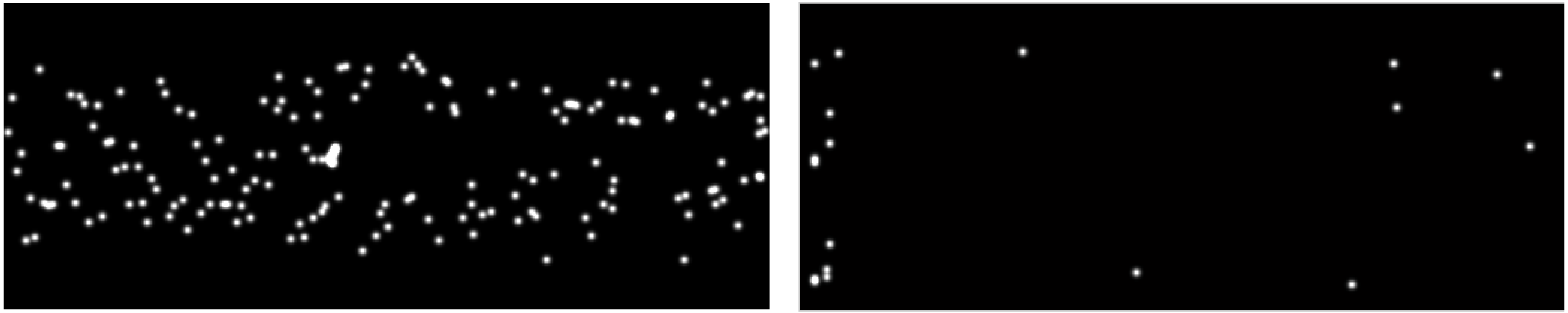
Example Code (4.0)

```
pd = mpheval(model,'u');
U = pd.d1';
pd = mpheval(model,'v');
V = pd.d1';
positions = pd.p;
X = positions(1,:)';
Y = positions(2,:)';
```

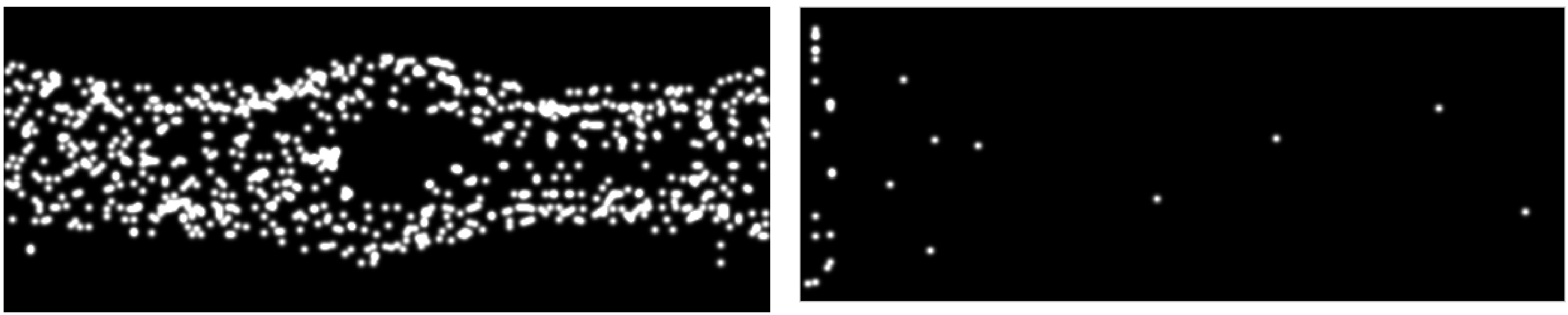


Particle images from COMSOL velocity field

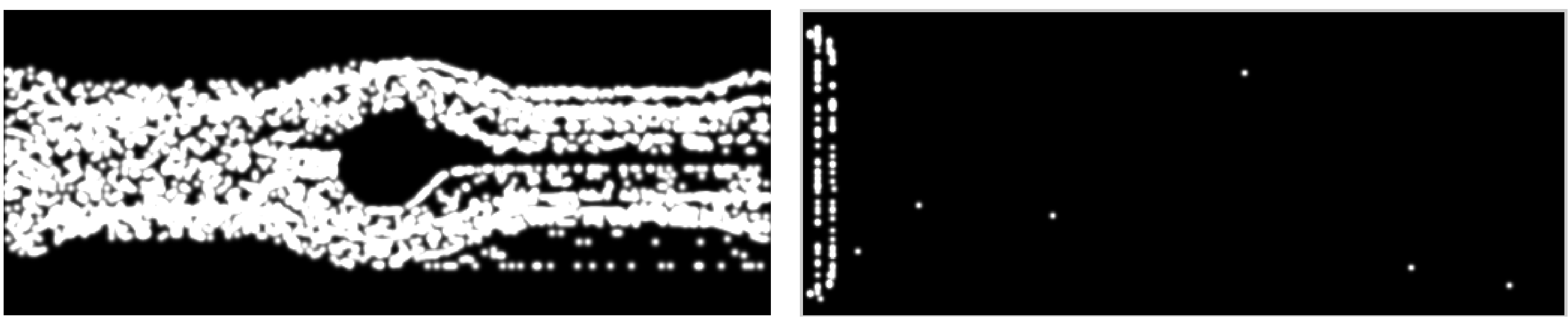
Low Concentration particle image



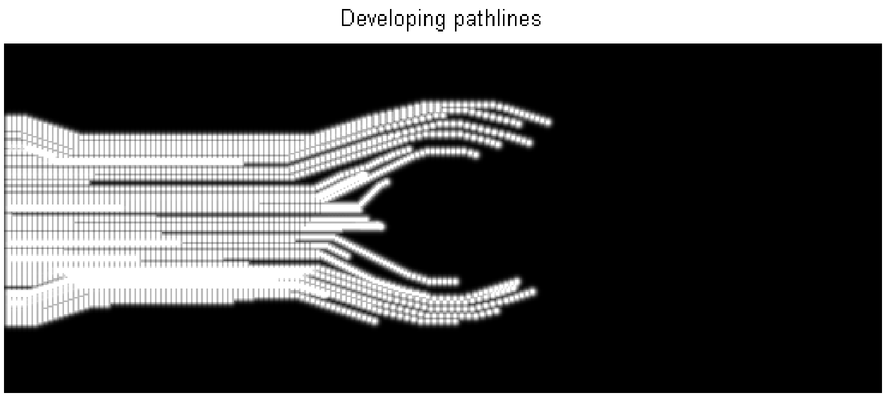
Medium Concentration particle image

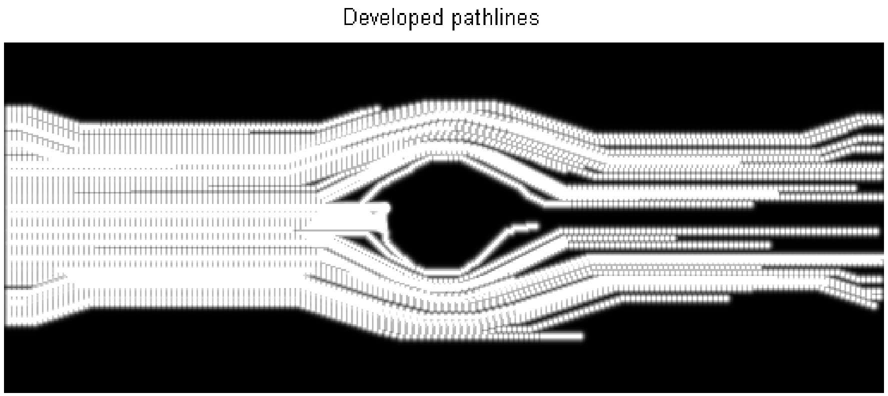


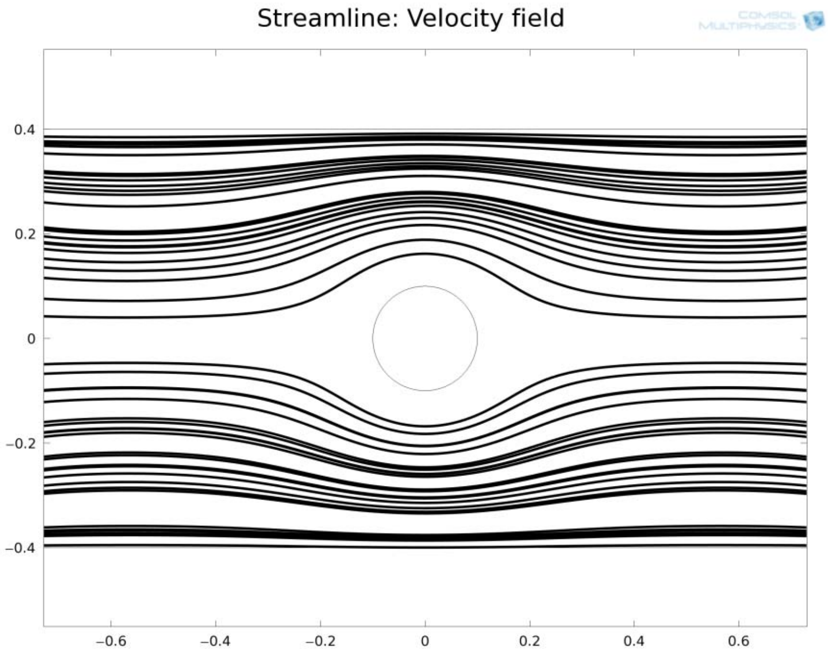
High Concentration particle image

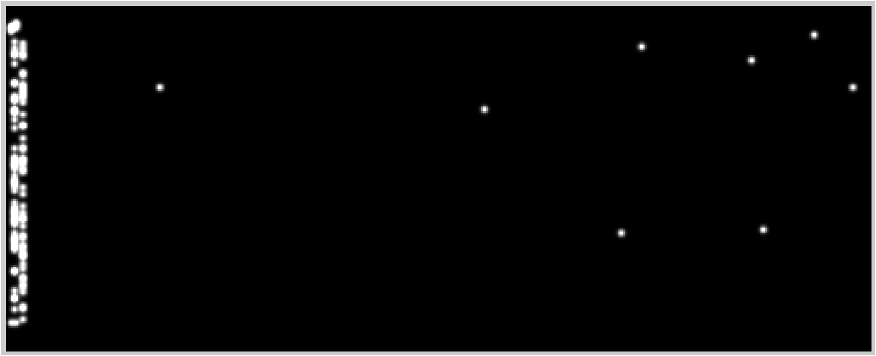


Streamlines from simulated images

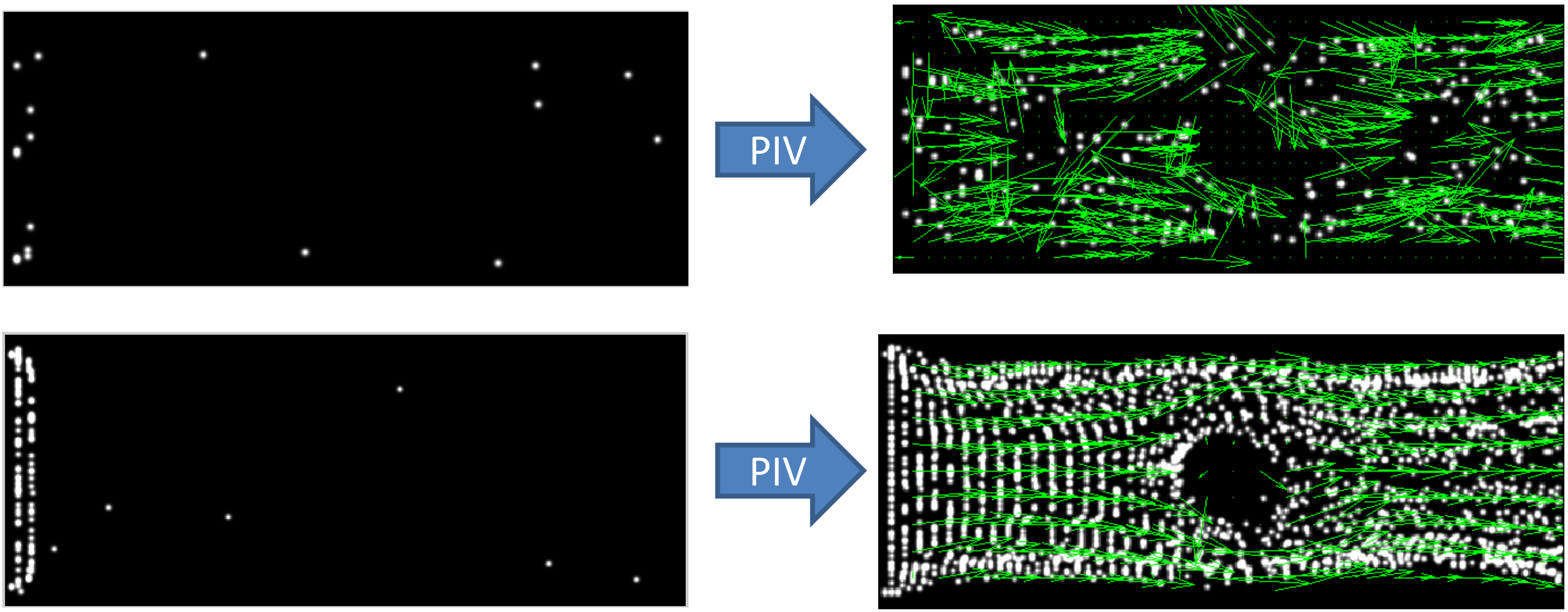








PIV using the simulated images



PIV algorithm using PIVlab - Time-Resolved Digital Particle Image Velocimetry Tool for MATLAB
PIVlab code by William Thielicke and Prof. Dr. Eize J. Stamhuis
http://pivlab.blogspot.com/

Conclusion

COMSOL was used for generating image sequences to be used for μPIV based work.

Simulated μPIV images based on expected physics under idealized experimental conditions and for arbitrary user designed flow circuits.

A good idea of required experimental conditions for efficient image acquisition is obtained.

The proposed method for particle image generation would help in designing better algorithms for μPIV : Most velocity field estimation algorithms based on imaging there is always a requirement for gold standard images with known velocities and experimental parameters.

References

1.Lindken,R., Rossi,M., Große,S. and Westerweel,J.
Micro-Particle Image Velocimetry (μPIV): Recent developments, applications, and guidelines, *Lab on a Chip*, **9**, 2551-2567 (2009).

2. Raffel, M., Willert, C. and Wereley S. Particle image velocimetry: a practical guide, 135-136, Springer-Verlag,(1998).

3. Santiago, J.G., Wereley, S.T., Meinhart, C.D., Beebe, DJ and Adrian, RJ,
A particle image velocimetry system for microfluidics, *Experiments in Fluids*, **25**, 316--319 (1998).

Thank you !!