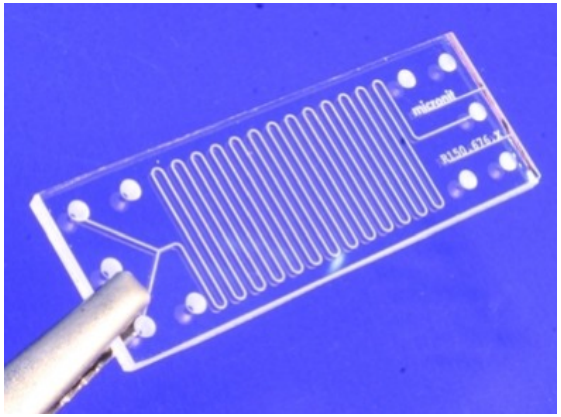
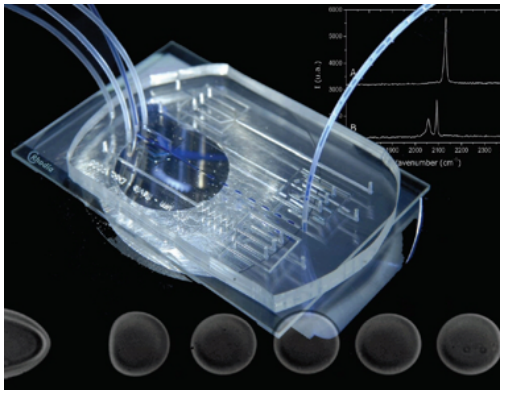
# Micro & Nanofluidics





# Fluidics

**Reynolds Number** (dimensionless)

$$\mathrm{Re} = \frac{inertial\ terms}{viscous\ terms} = \frac{\rho v D}{\eta}$$

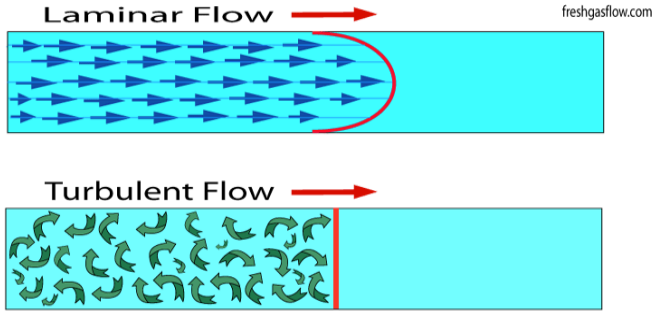
ρ : fluid density
v : fluid speed
η : fluid viscosity
D: diameter of the pipe

**Inertia**: resistance of an object to any change in its motion (to keep moving in a straight line at constant velocity, or to keep still)

**Viscosity**: fluid resistance flow (to gradual deformation by shear stress)

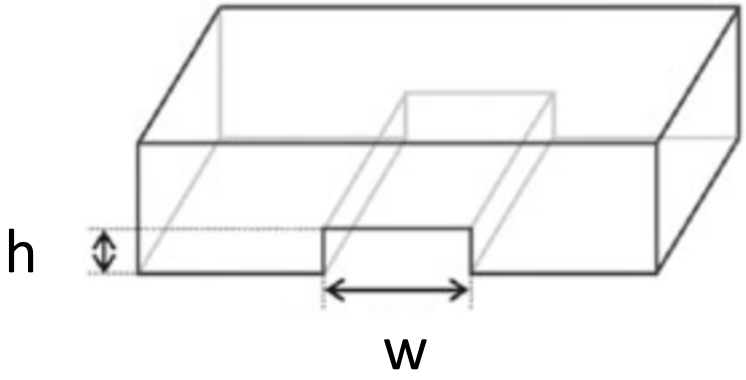
Re<500 : **laminar flow**
(fluid flows in parallel layers)

Re>2000 : **turbulent flow**



# Reynolds number

For non circular channels, use the hydraulic diameter to calculate the Reynolds number: $D=D_H$




Definition: $D_H = \frac{4A}{P}$

$D_H = d$ *pipe diameter*

$D_H = \frac{2}{\frac{1}{h} + \frac{1}{w}}$ *channel height and width*

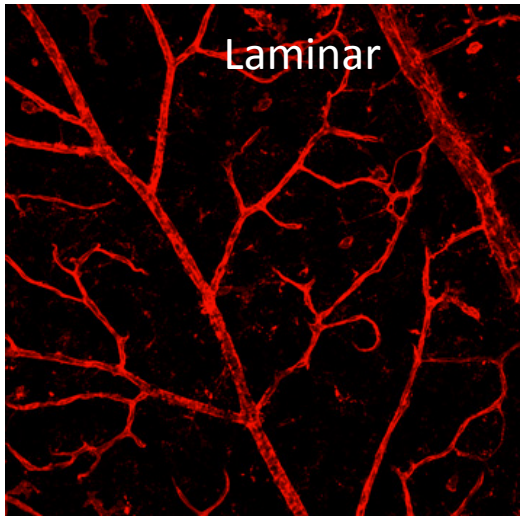
A: cross section area
P: wetted perimeter

Work on exercise 1

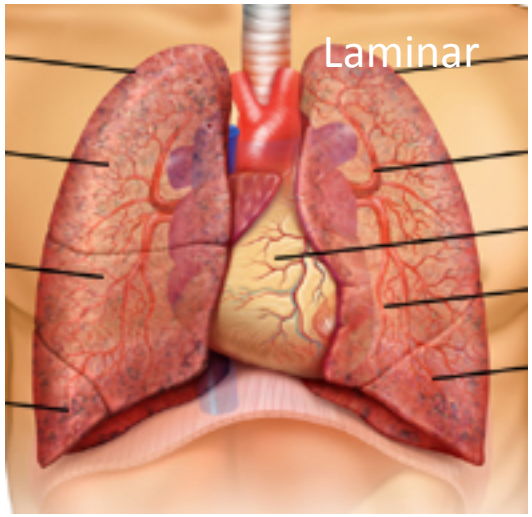
# Fluidics








Blood in blood capillaries




Air in airway capillaries

# Low Reynolds number prevail not only in the micro world…

B. H. Weigl, R. L. Bardell, and C. R. Cabrera, "*Lab-on-a-chip for drug development*", Advanced Drug Delivery Reviews **55** (3), 349 (2003).

$D = 100\,m$

$v = 10\,m/year = 0.3\,\mu m\,s^{-1}$

$\eta = 10^{10}\,kg\,m^{-1}\,s^{-1}$

$\rho = 10^{3}\,kg\,m^{-3}$

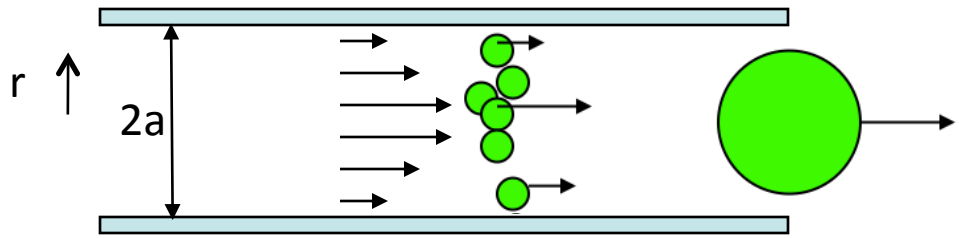
$$\mathrm{Re} = \frac{\rho v D}{\eta} = 3 \cdot 10^{-12} << 1$$

Viscous terms dominate and we have laminar flow

In a laminar flow, the viscous terms dominate
Image = honey flowing in a channel

# Liquid and sample transport - Pressure driven flow

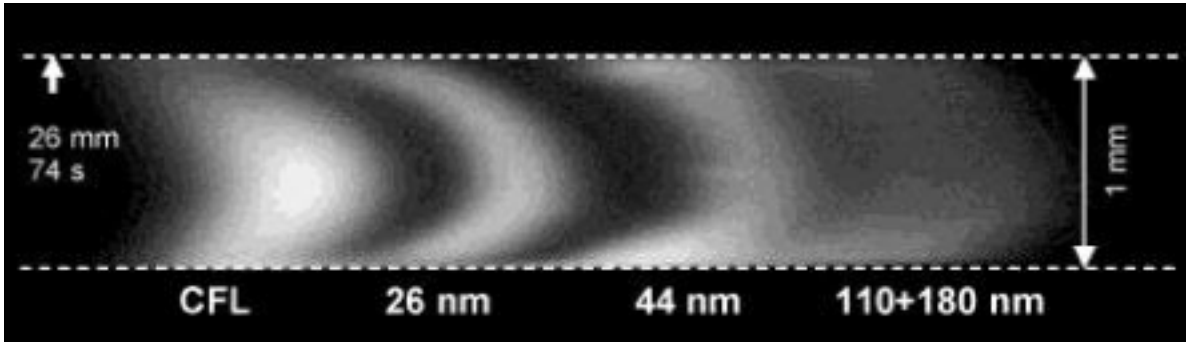
Stick-boundary conditions (u=0 at r= ±a) give a parabolic flow profile:




$$u(r) = u_{\max}\left(1 - \frac{r^2}{a^2}\right)$$

*a* is the tube radius

Particles at the periphery travel slower than particles in the center.
A plug of sample is therefore spread out as it travels in the tube which may lower resolution of a fluidics system.
It can also be useful: Large particles are excluded from the edges and travel on average faster than small particles, that can be closer to the edges (**hydrodynamic chromatography**).



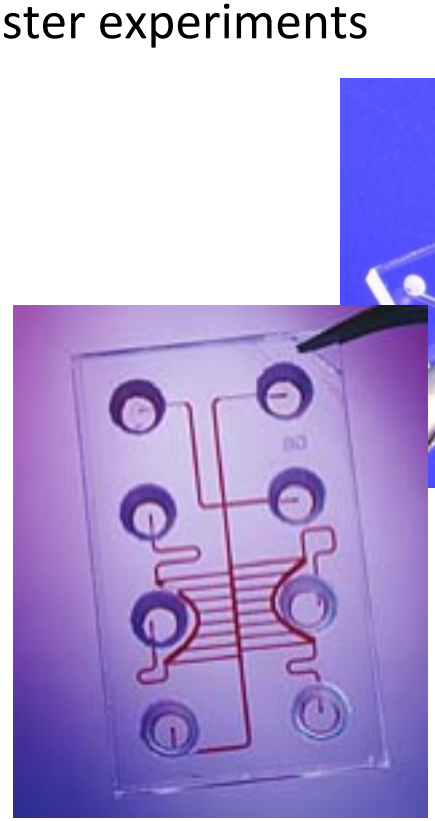

University of Twente – group of Albert van den Berg
pubs.acs.org/doi/pdfplus/10.1021/ac034663l

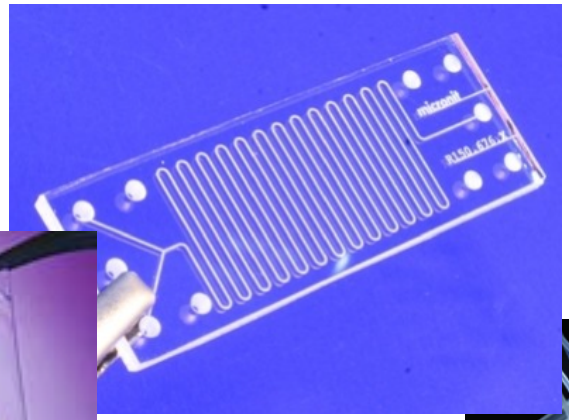
# Micro and nanofluidics - Lab on a chip

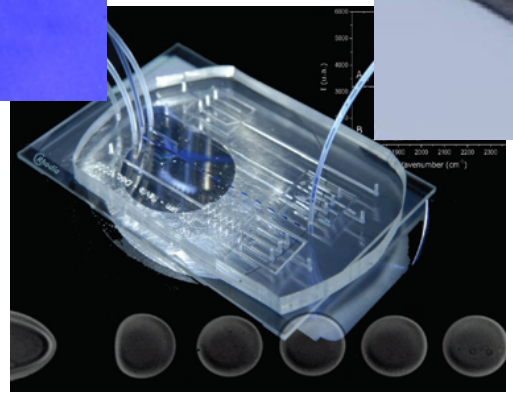
Micro and nanofluidics: Can be used for fundamental studies made possible thanks to the properties of the small channels

Lab on a chip: application of micro and nanofluidics- analysis and diagnostics oriented

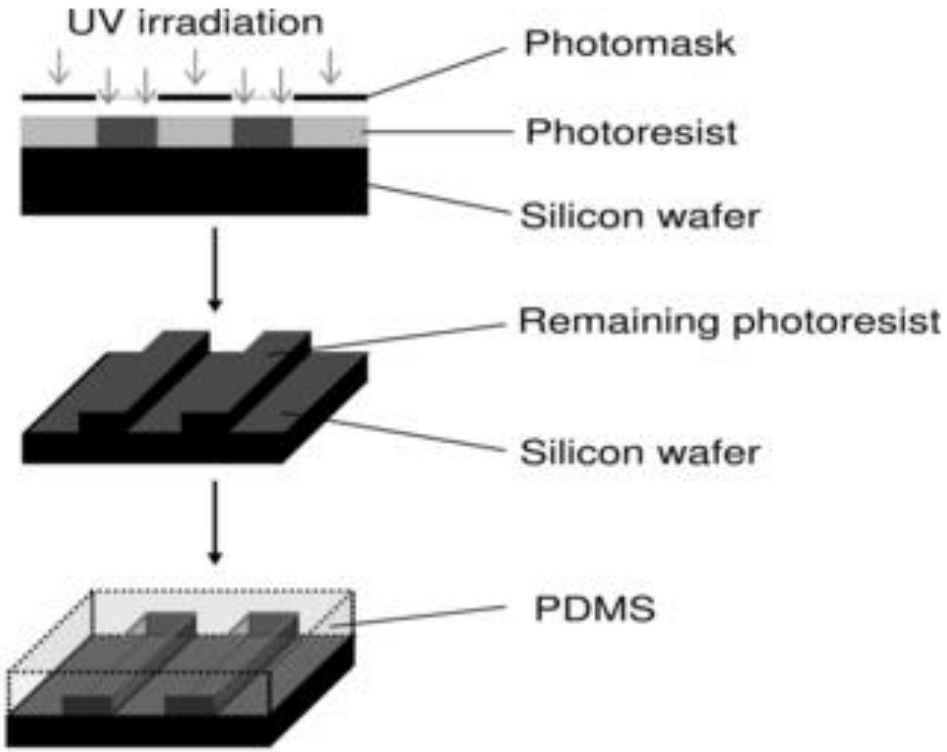
Advantages over traditional methods:
-smaller sample and reagent amount needed
-faster experiments

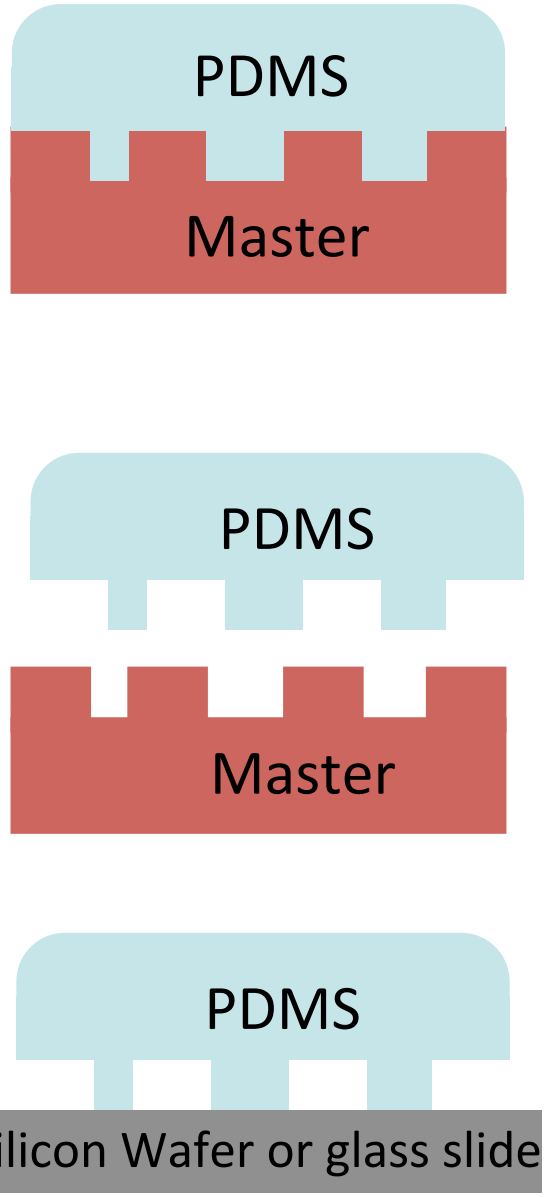






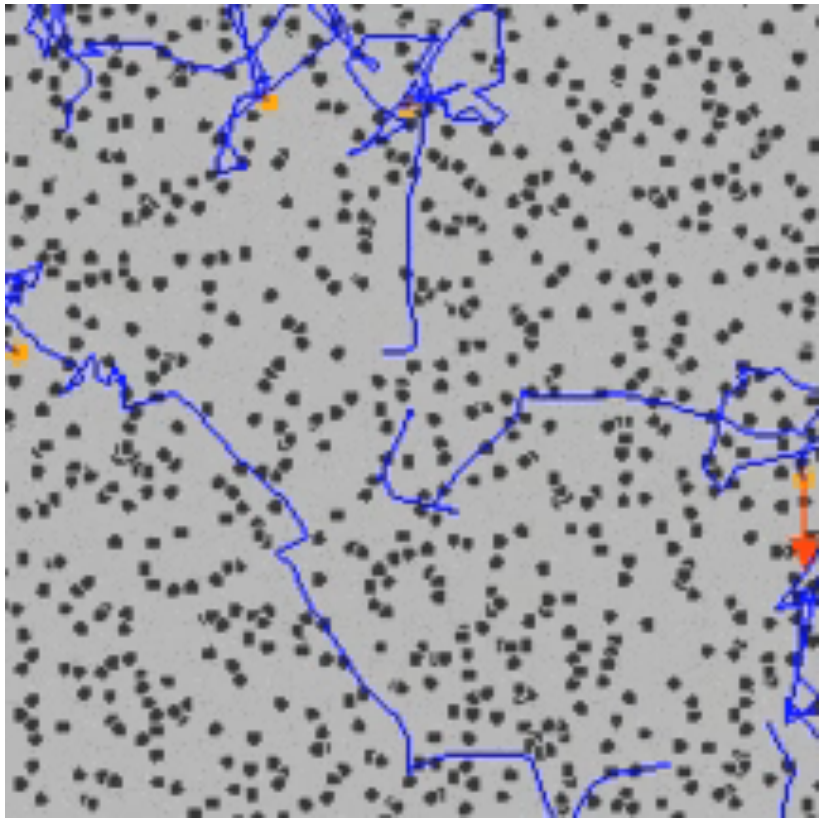
# Fabrication – Photolithography and Soft Lithography

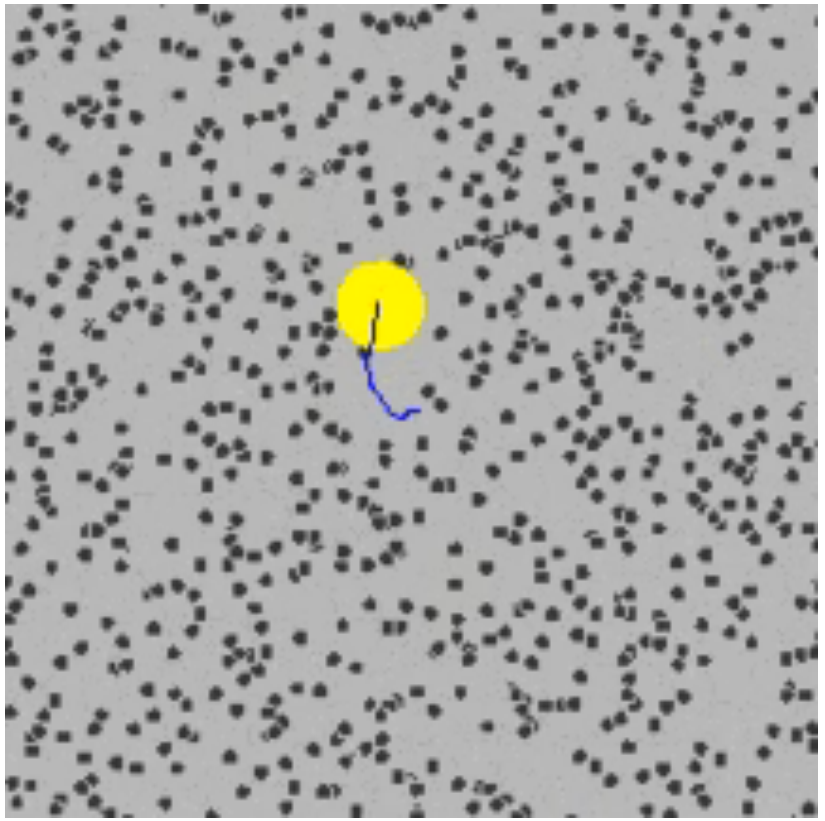


Diffusion: becomes important in microfluidics due to the small size of the channels.

Brownian motion: random movement of molecules/objects in a fluid due to the fast moving of atoms in the fluid.





# Diffusion

## Diffusion coefficient D: Einstein's relationship:

$$D = \mu k_B T = \frac{k_B T}{6\pi\eta a}$$

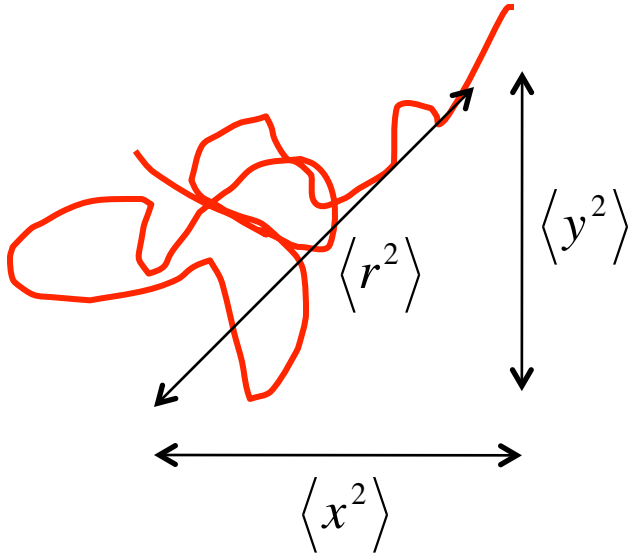
$k_B$: Boltzmann constant=1.38064852 × $10^{-23}$ $m^2$ kg $s^{-2}$ $K^{-1}$
T: temperature
η: viscosity of the fluid
μ: mobility of the particle
a: particule radius

In one dimension $\left\langle x^2 \right\rangle = 2Dt$

Movement in each orthogonal direction is *independent*.

Two dimensions $\left\langle r^2 \right\rangle = \left\langle x^2 \right\rangle + \left\langle y^2 \right\rangle = 4Dt$

Three dimensions $\left\langle r^2 \right\rangle = \left\langle x^2 \right\rangle + \left\langle y^2 \right\rangle + \left\langle z^2 \right\rangle = 6Dt$

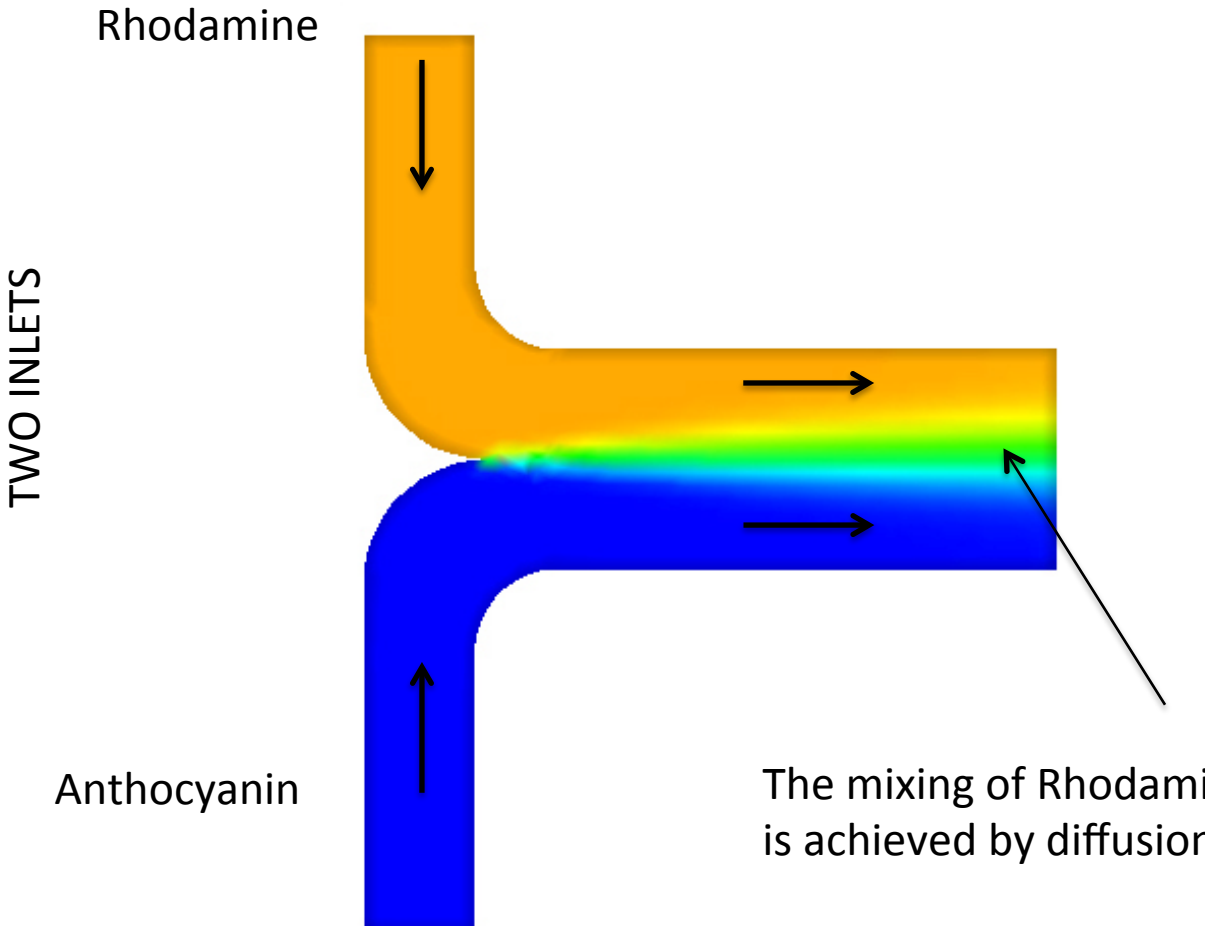



$\langle \quad \rangle$ here means averaging over many attempts each one of duration *t*.

# Diffusive mixer

In general in microfluidics, the flow is laminar and there is no convective mixing.

Due to short distances, instead diffusion becomes important.




The mixing of Rhodamine and anthocyanine is achieved by diffusion only (no turbulent flow)

Work on exercises 2 and 3

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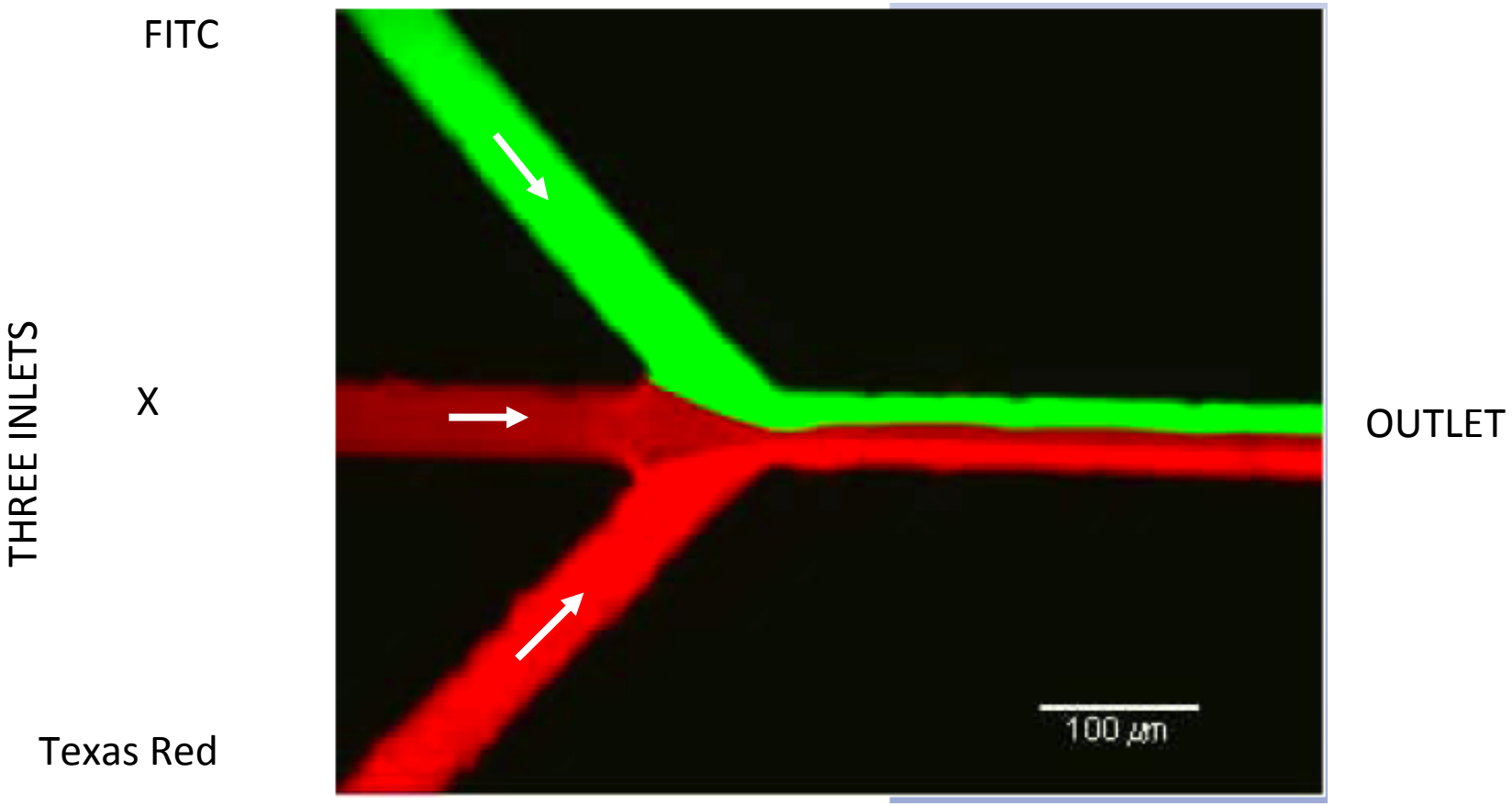



The widths of the streams at the outlet are functions of the relative flow rates at the inlet channels.

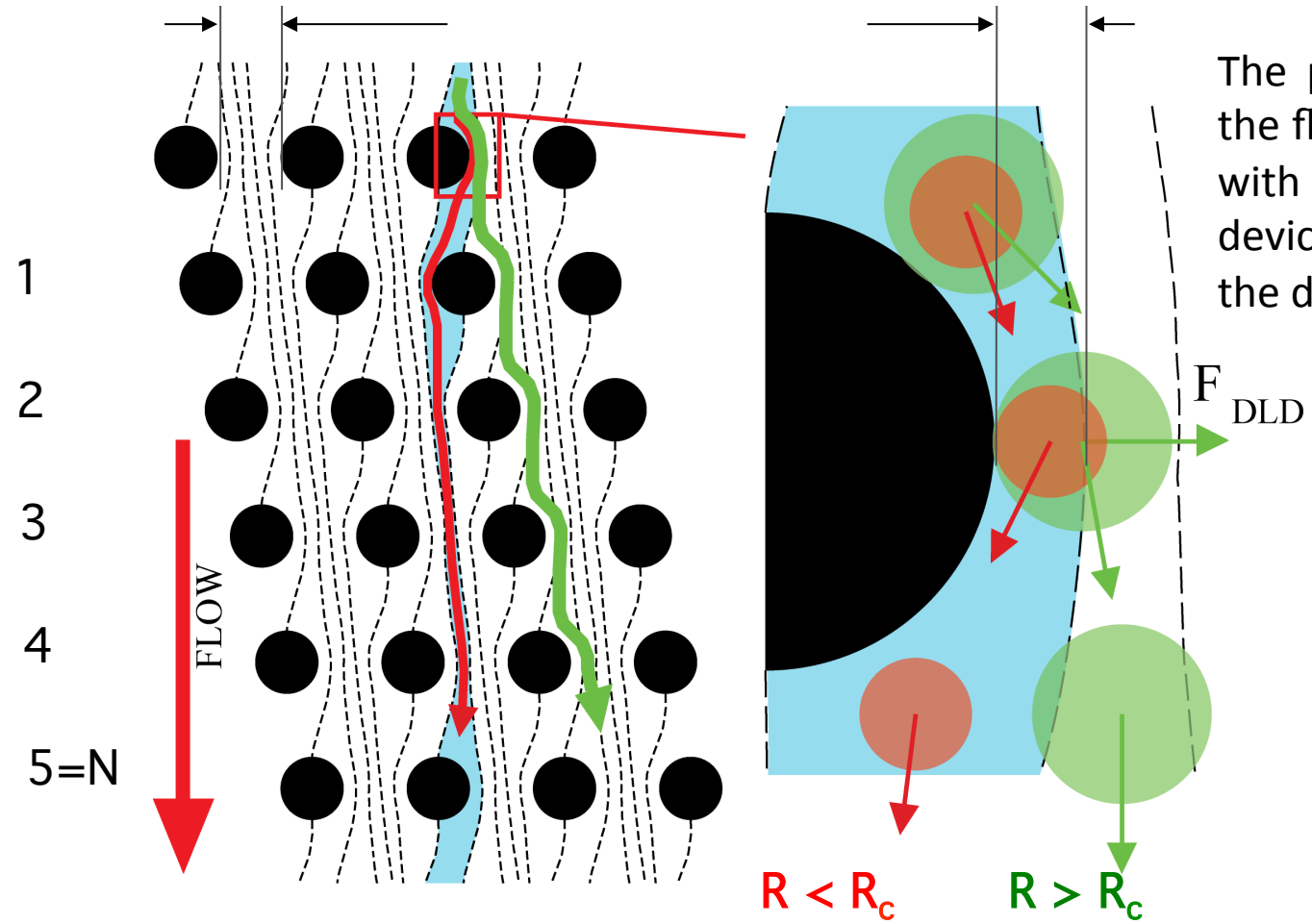
# Another example of microfluidic device

# Deterministic lateral displacement:
## *Bumper array*

***Basic idea***: streamlines constitute potential trajectories. Particles shift streamline, and thus trajectory, as a response to a force (here steric: they "bump" into the obstacles )

Critical Radius: $R_c$

$$Rc = \frac{\text{distance between obstacles}}{\text{period of array}}$$




The particles with R<Rc follow the flow direction. The particles with R>Rc travel through the device at an angle compared to the direction of the flow.

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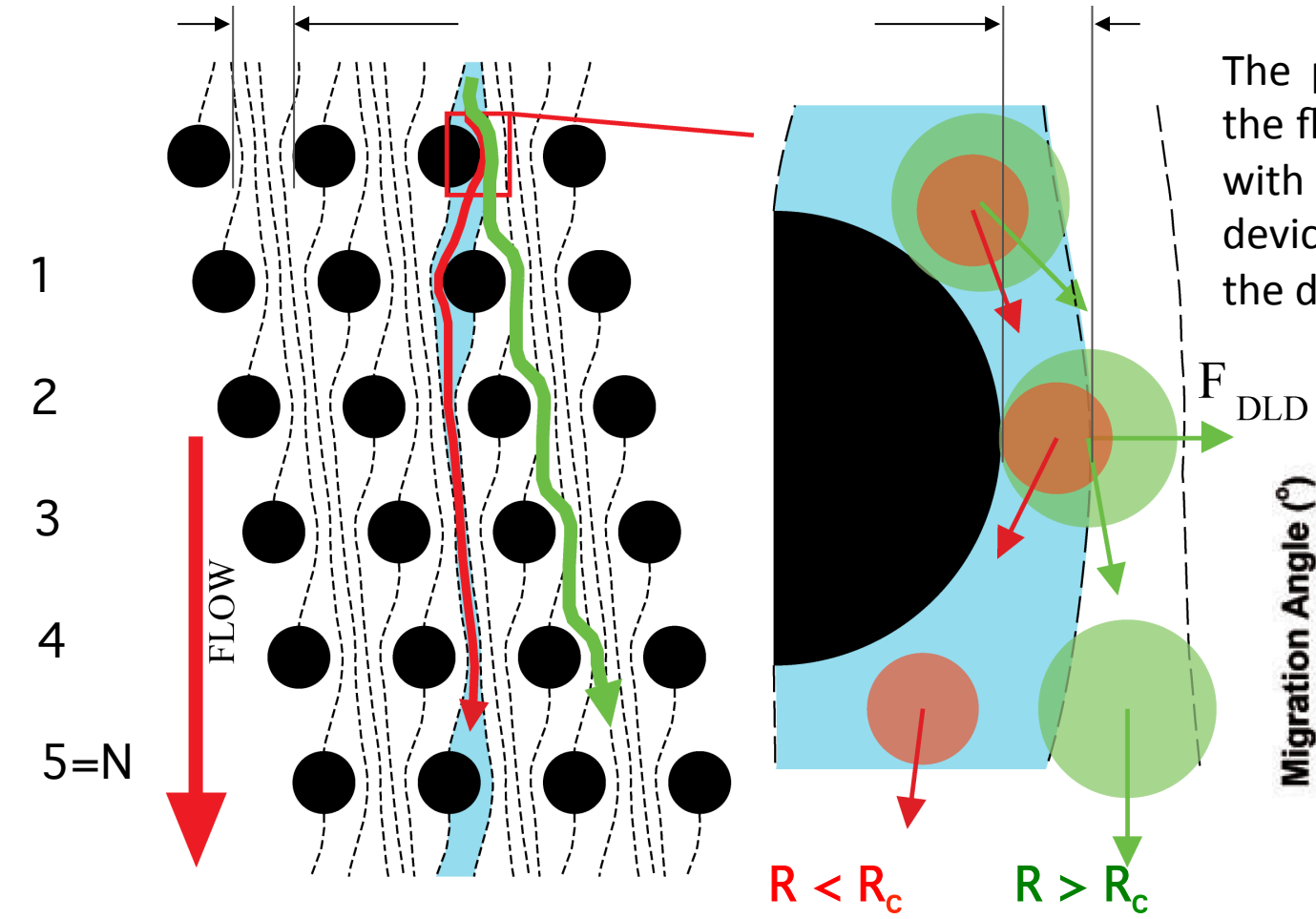


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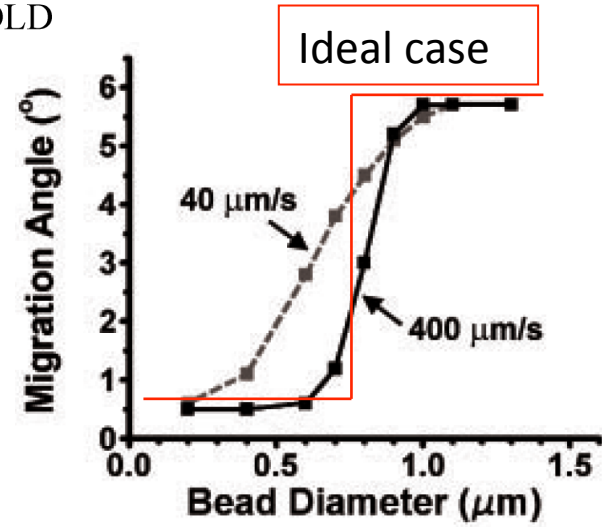


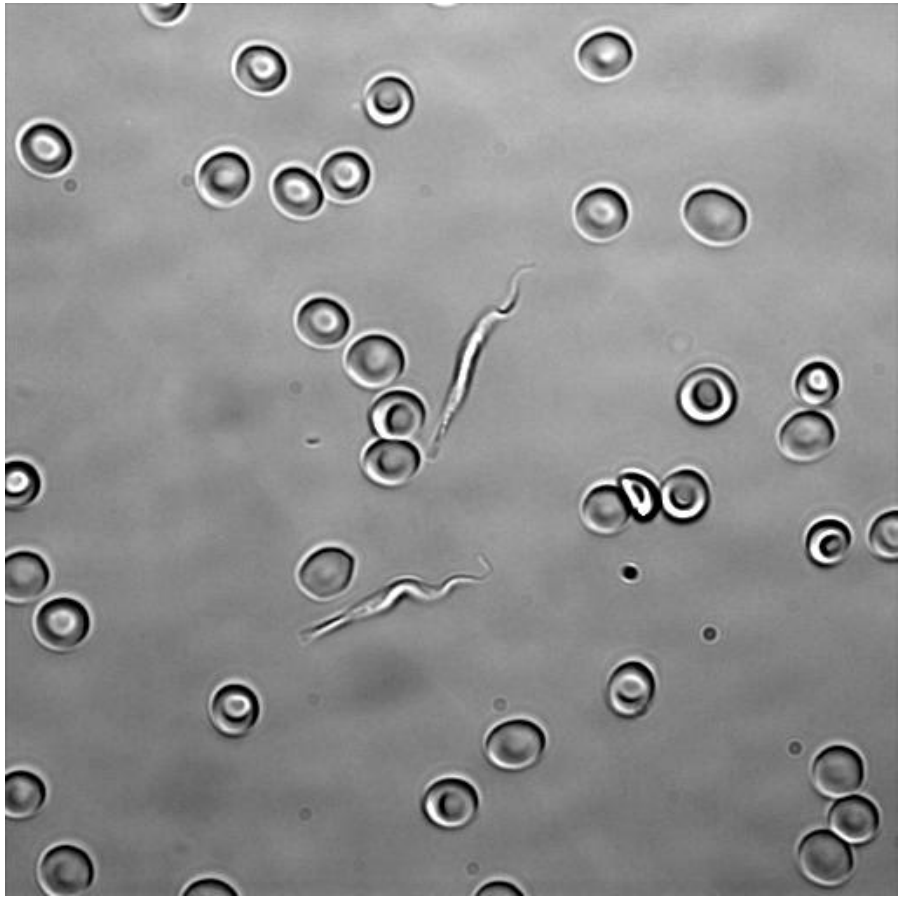
# Application – Ultrasimple label-free sorting of trypanosomes

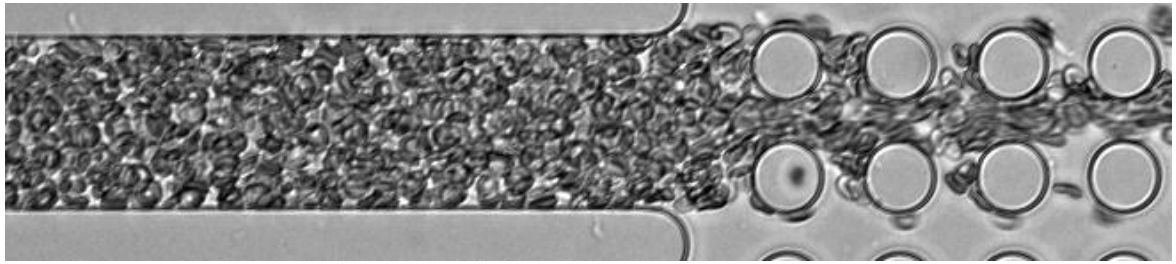
*Trypanosoma brucei* -> sleeping sickness.
•Fatal (100%) disease.
•Fatal (5%) treatment.
→Imperative to minimize false negatives as well as false positives.

Current diagnosis relies on enrichment by ion exchange chromatography and centrifugation.

Simpler and cheaper methods needed that are adapted to use in remote areas.

Major challenge – Need to detect as low concentrations as 100 parasites per mL.





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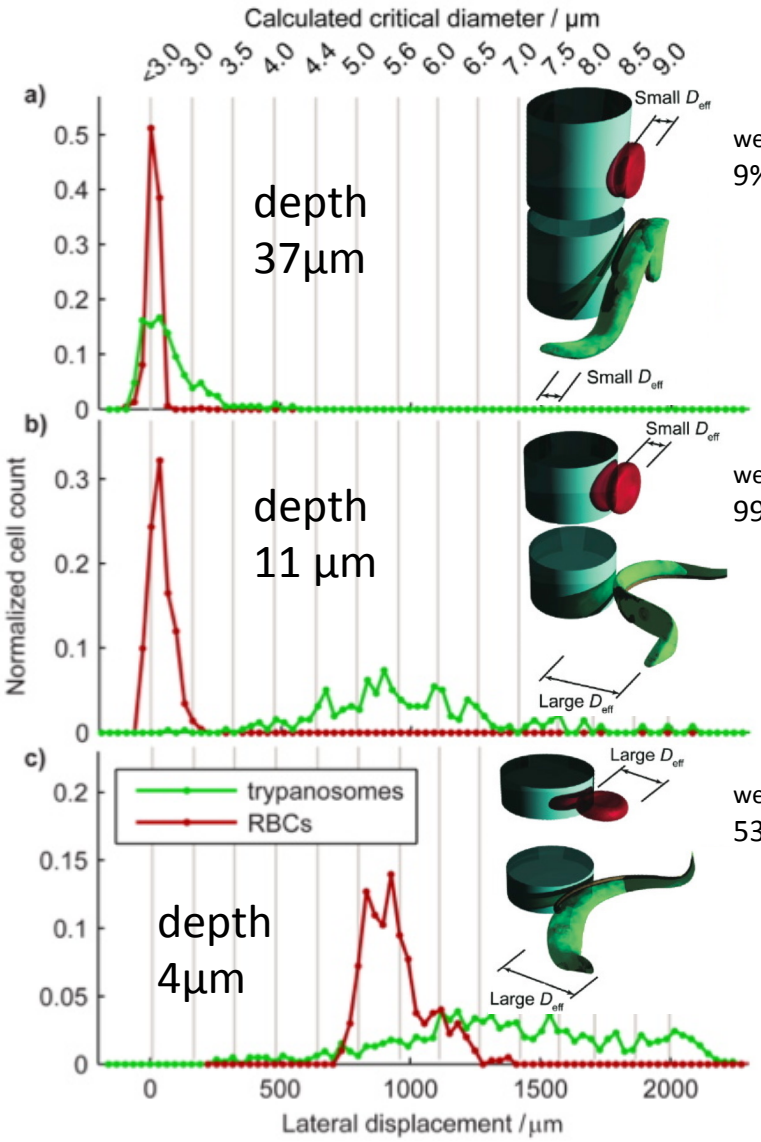
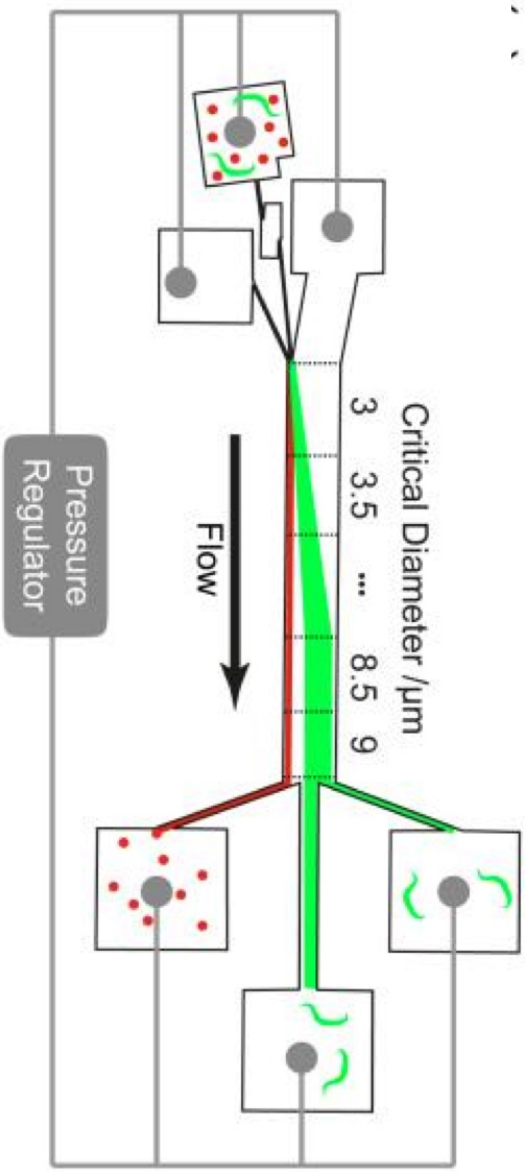



At 99% RBC rejection

we have a capture efficiency
9%

we have a capture efficiency
99.5%

we have a capture efficiency
53%




Holm, Beech, ... LabChip2011