X-Ray Studies of Bio-Matter in Microfluidic Sample Environments

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Workshop on Evolution and Control of Complexity:

Key Experiments Using Sources of Hard X-Rays

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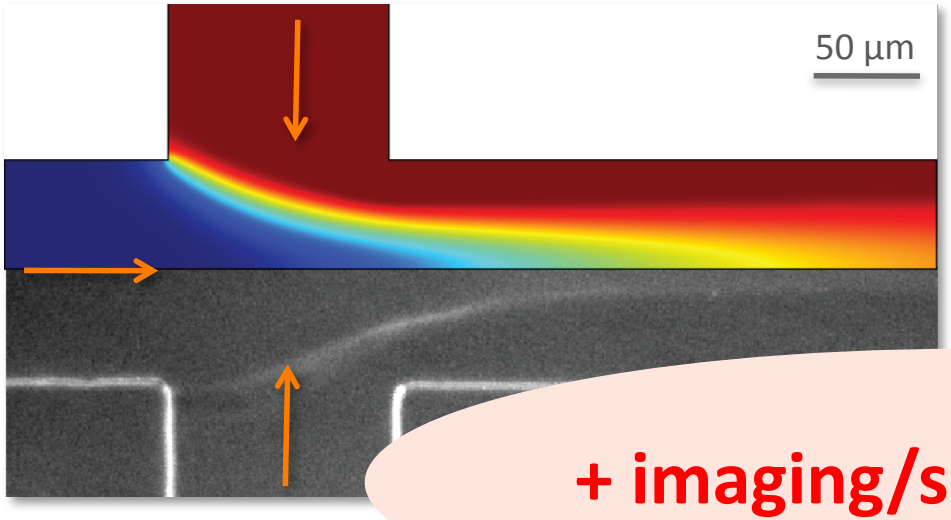
Courant Research Centre
Nano-Spectroscopy and X-Ray Imaging

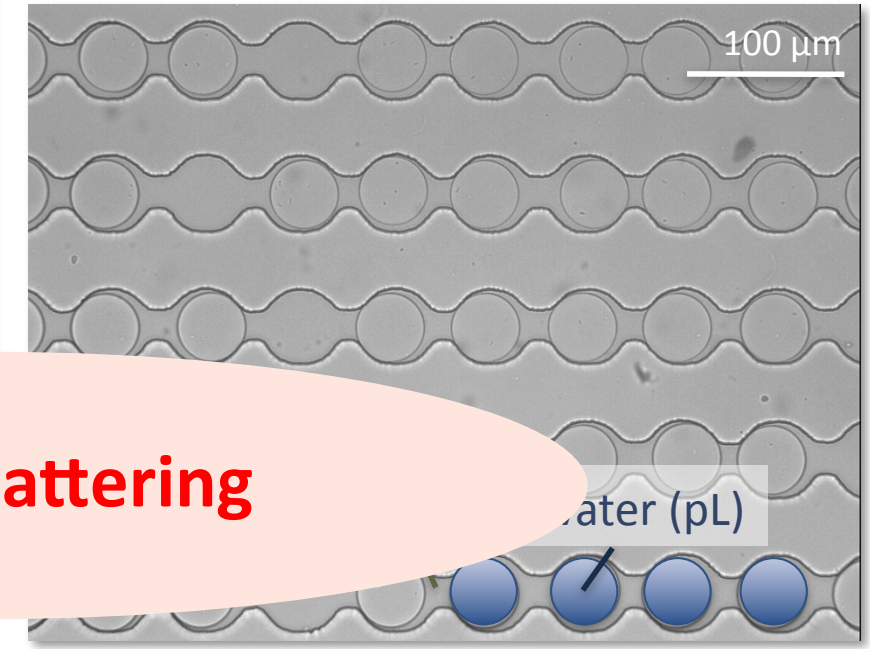
GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN

“Tools” on the micrometer scale

micrograd ients

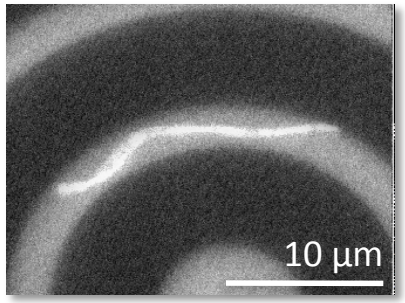


segmented flow

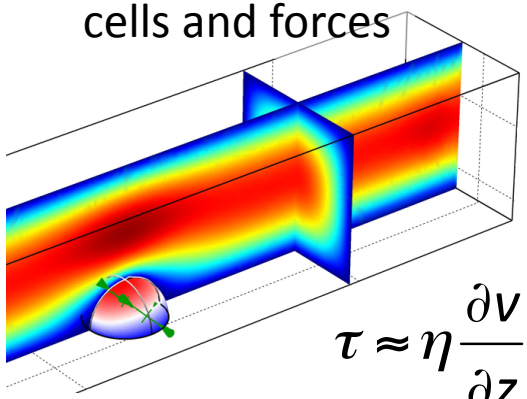


+ imaging/scattering

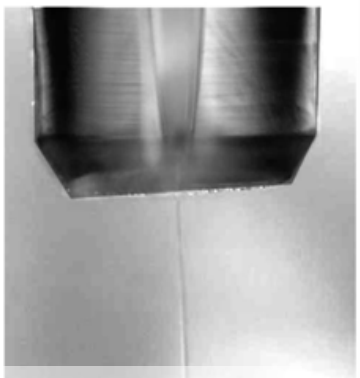
geometric confinement



cells and forces



$$\tau \approx \eta \frac{\partial v}{\partial z}$$



high shear rates

Laminar flow in microchannels

Navier-Stokes equation: $$\rho \frac{\partial}{\partial t}\vec{v} + \rho\left(\vec{v}\nabla\right)\vec{v} = -\nabla p + \eta \nabla^2 \vec{v}$$

inertial forces: $\propto \rho v^2/L$ viscous forces: $\propto \eta v/L^2$

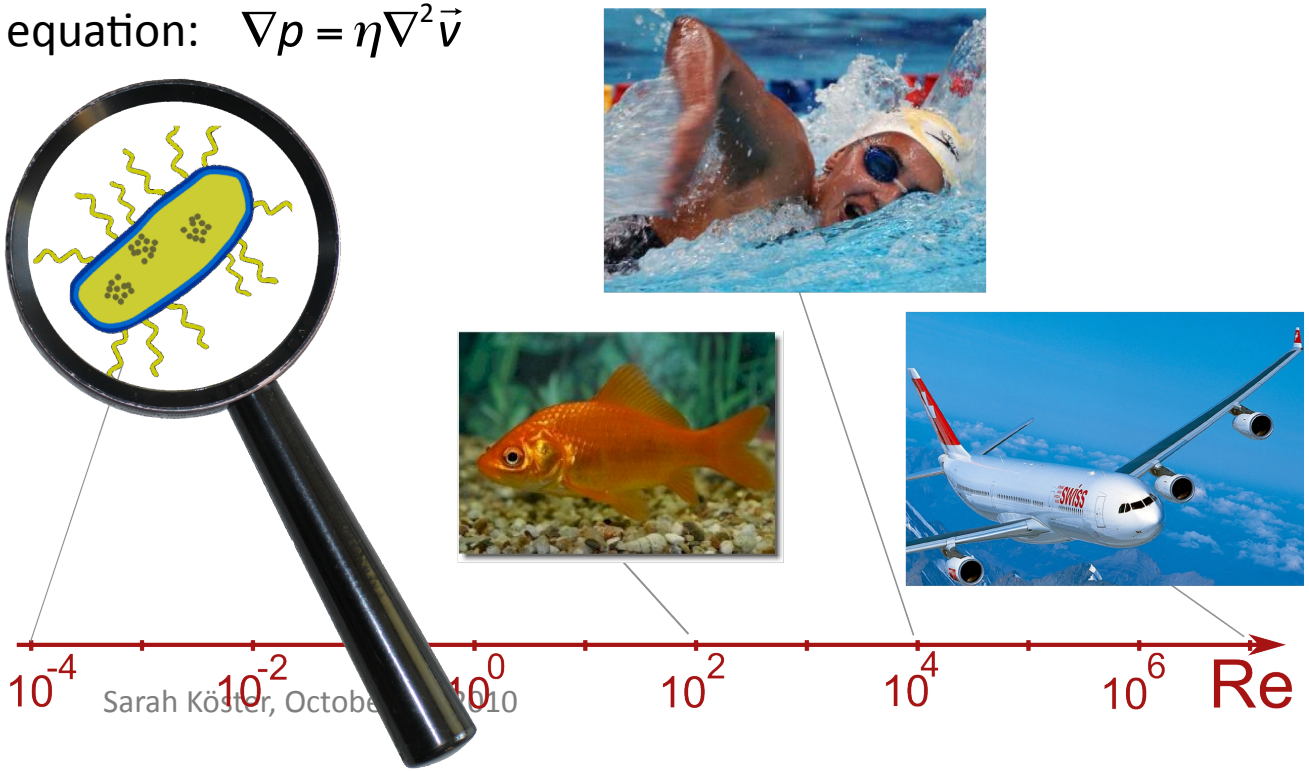
→ dimensionless Reynolds number: Re = inertial forces/viscous forces= $\rho vL/\eta$

→ in microchannels: Re ~ 10^{-3} → viscous forces dominate

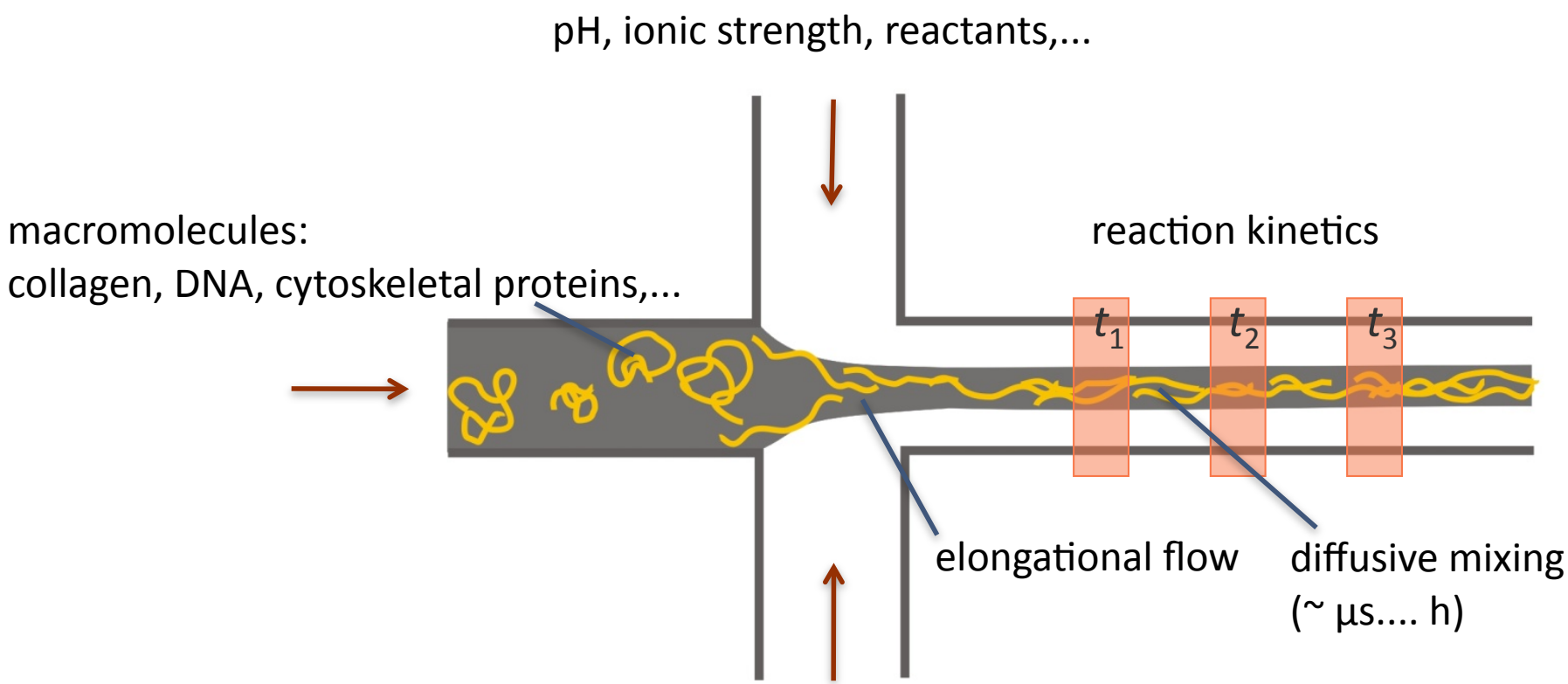
→ time independent Stokes equation: $\nabla p = \eta \nabla^2 \vec{v}$

→ laminar flow

→ defined, controlled

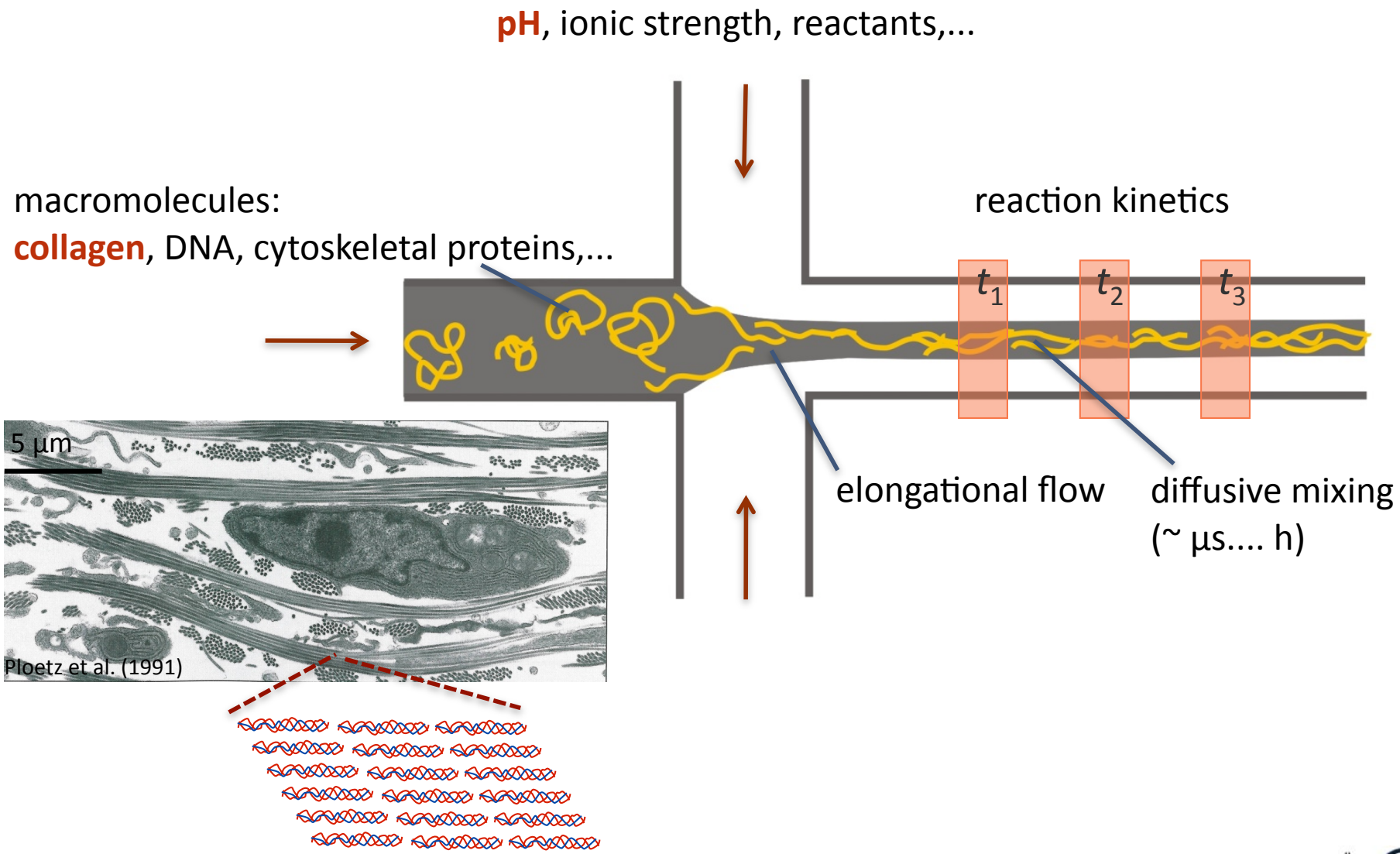


Self-assembly of proteins

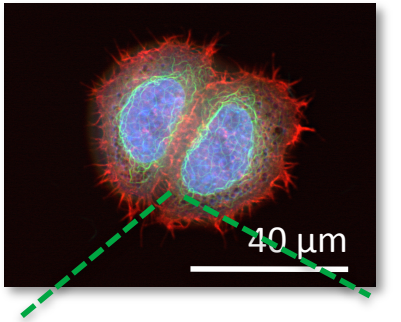


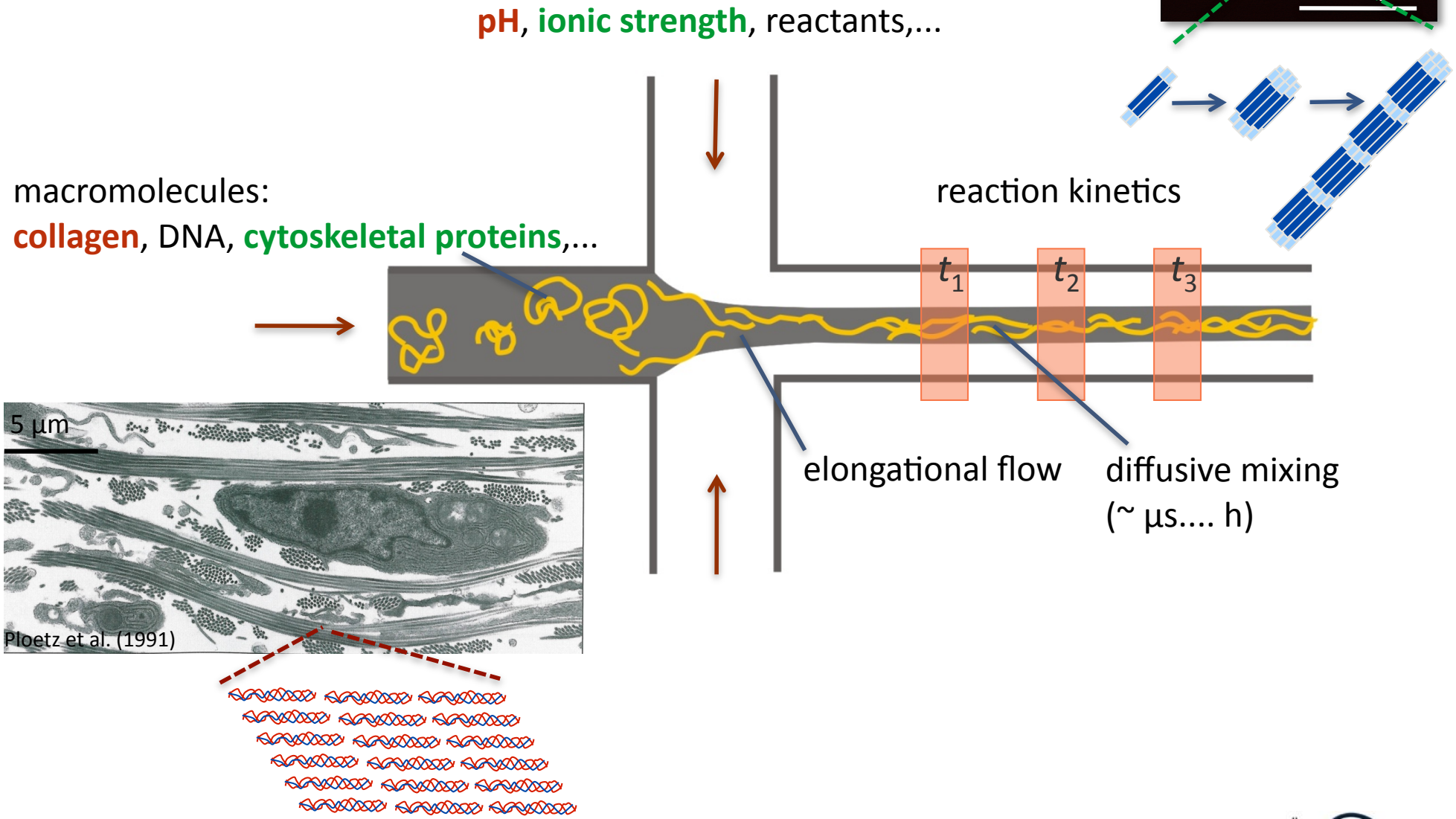
channel dimensions: ~ 100 µm

Self-assembly of proteins



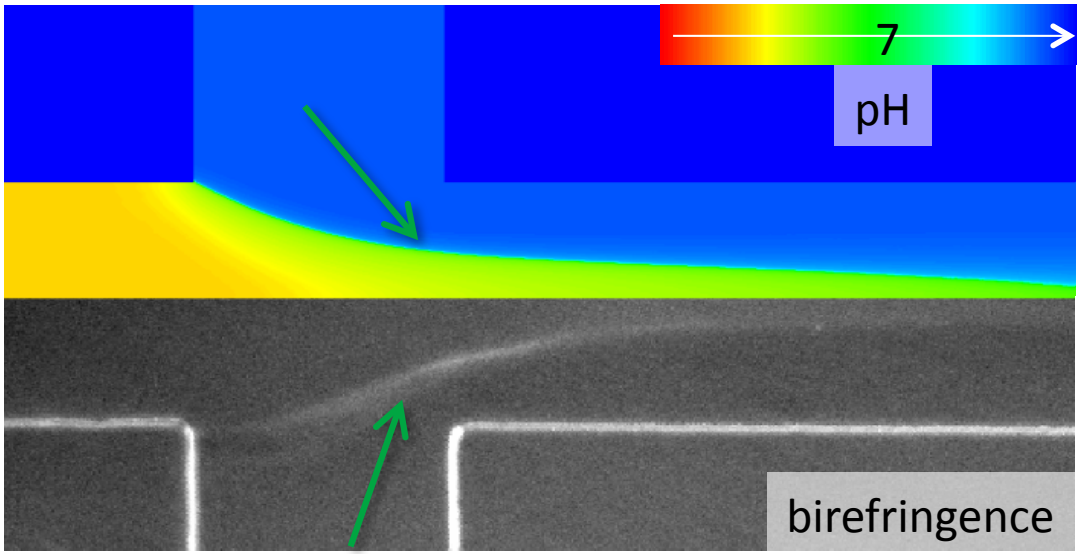
Self-assembly of proteins



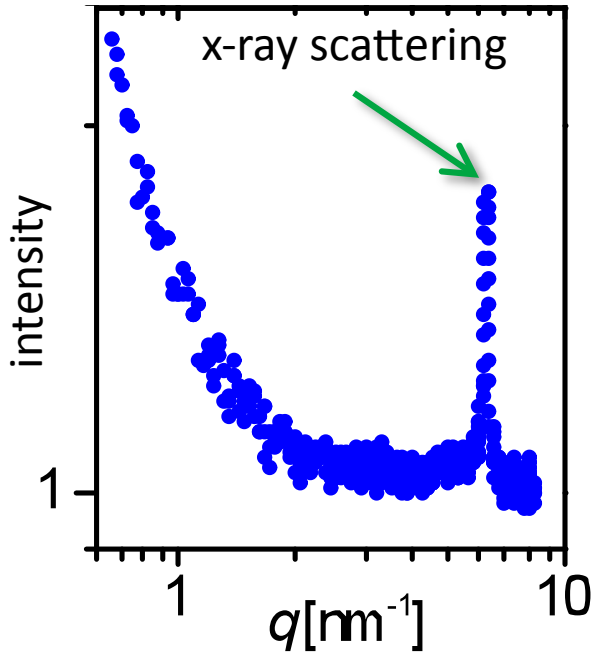


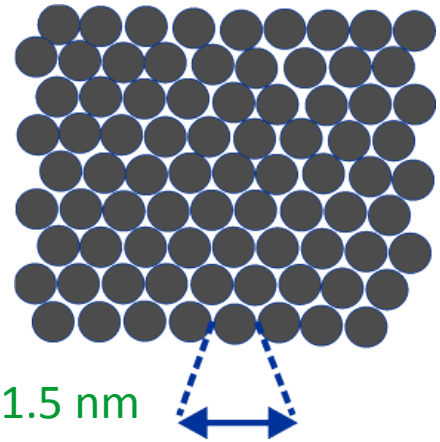
Finite element modeling and experiment

Köster et al, Langmuir 2007
Köster et al, Biomacromolecules 2008



assembled collagen

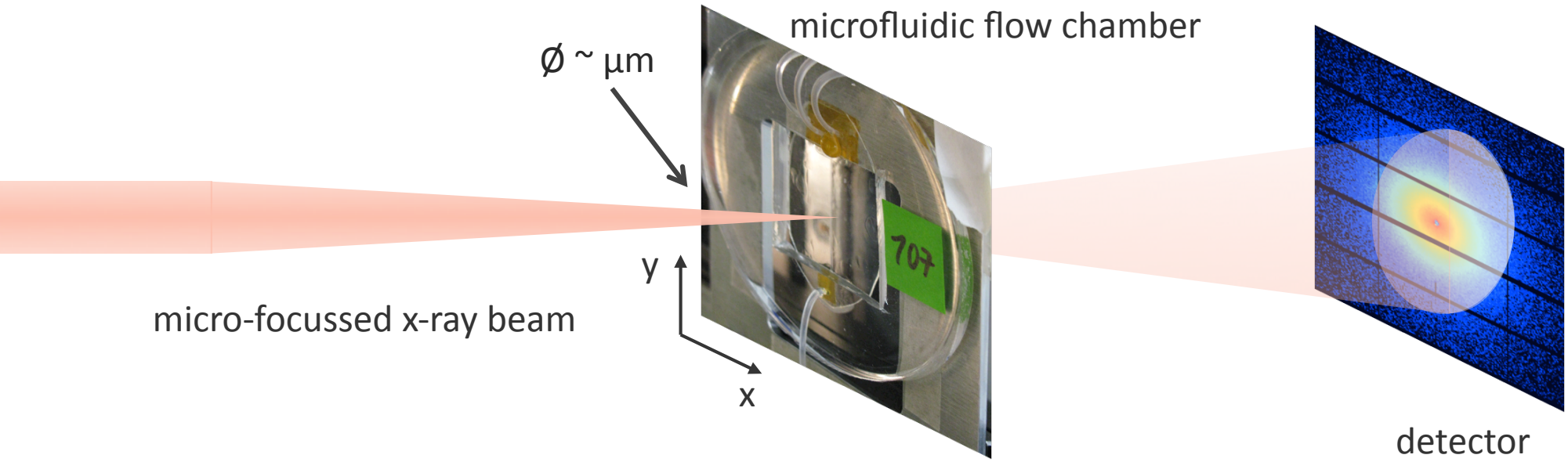




d ~ 1 - 1.5 nm

Micro focussed x-ray scattering

synchrotron – experiments
ESRF (Grenoble) – ID10b, ID13, ID02
SLS (Villigen) – cSAXS



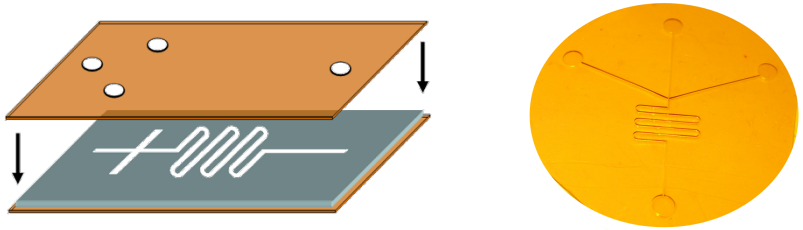
µ-fluidic sample environments

stainless steel – Kapton

Otten et al. J. Synchr. Rad. 2005

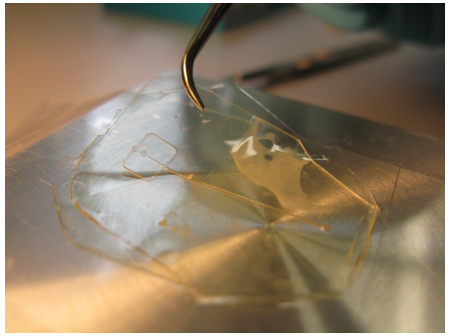
PDMS – Kapton

Dootz et al., Small 2007



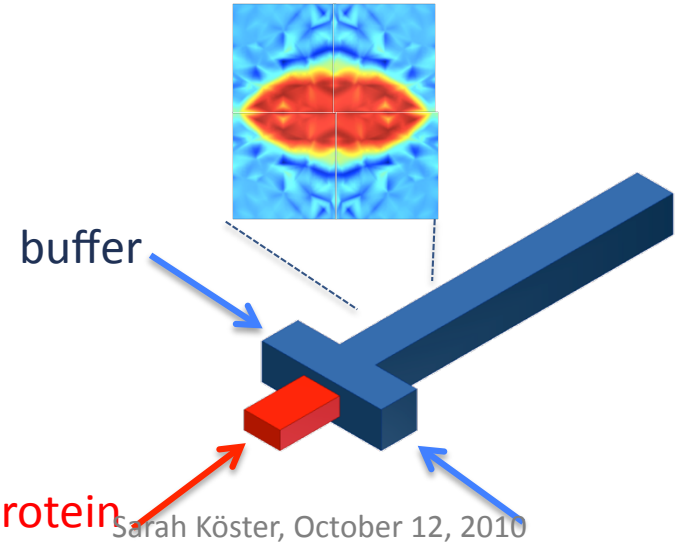
lateral size range ~ 1 – 1000 µm
channel depth ~ 0.5 - 250 µm

UV curable adhesive



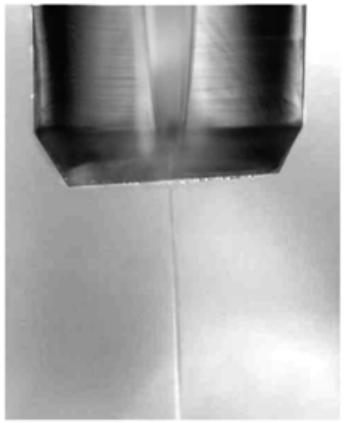
Brennich et al., submitted

3D structures



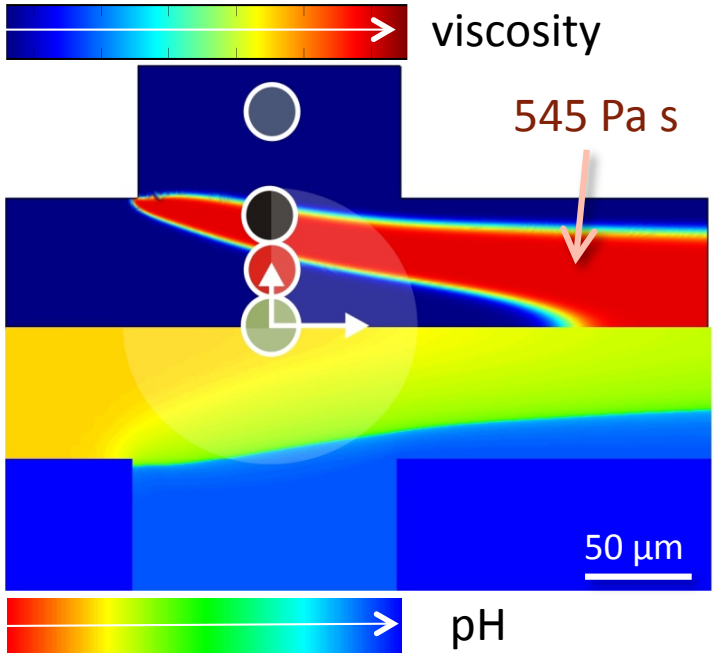
liquid jet

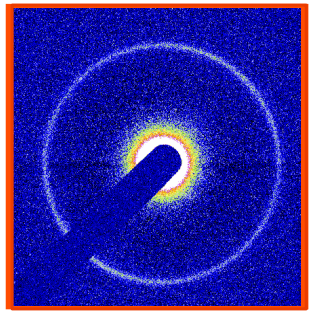
Priebe et al. New J. Phys. 2010

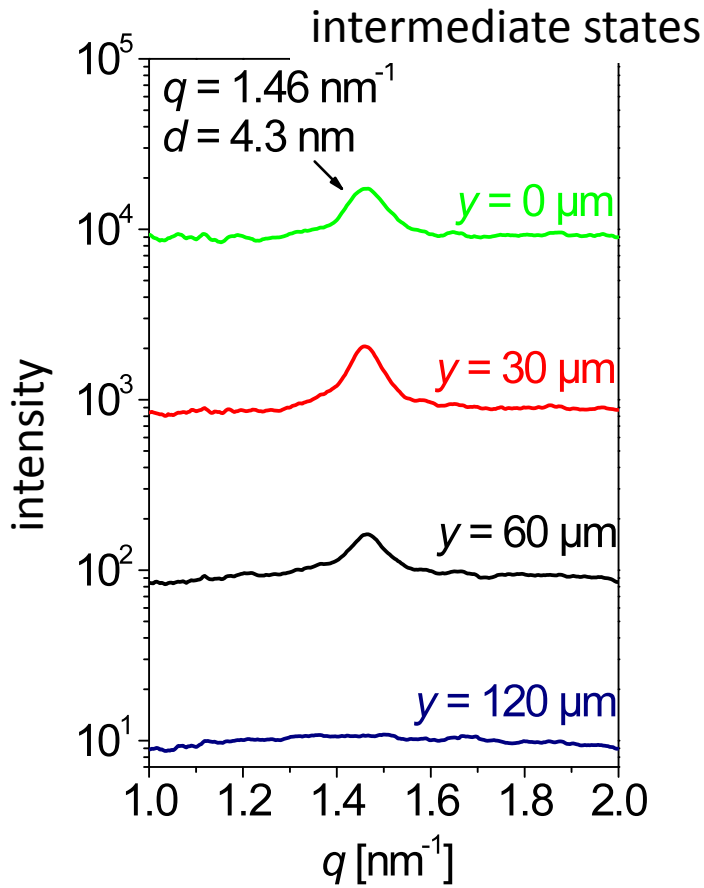


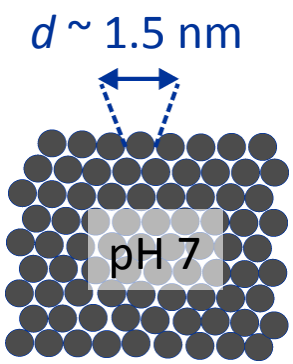
Micro x-ray diffraction on collagen

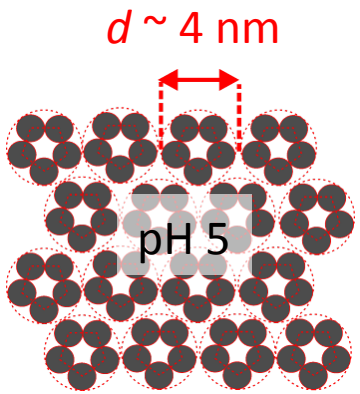
Köster et al, Langmuir 2007
Köster et al, Biomacromolecules 2008

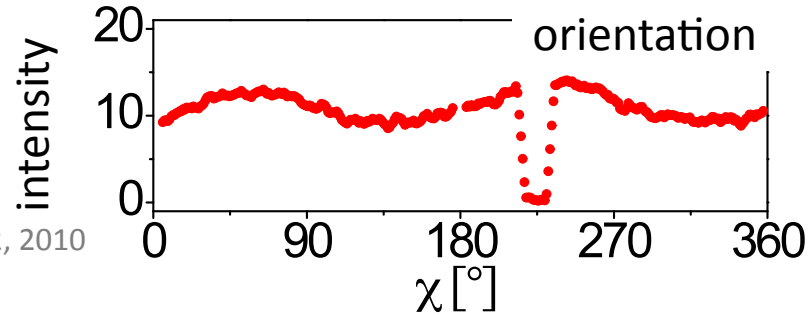




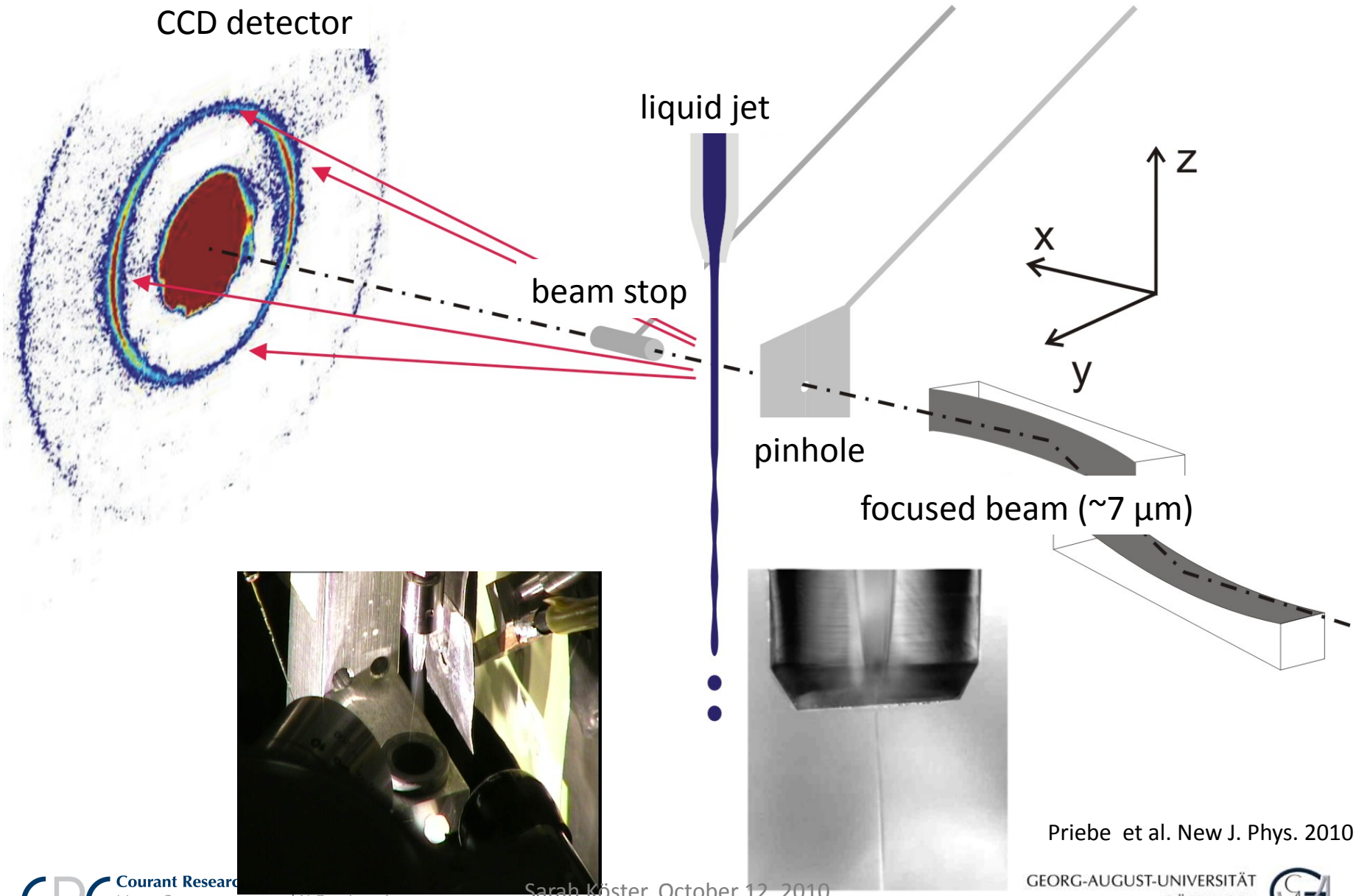






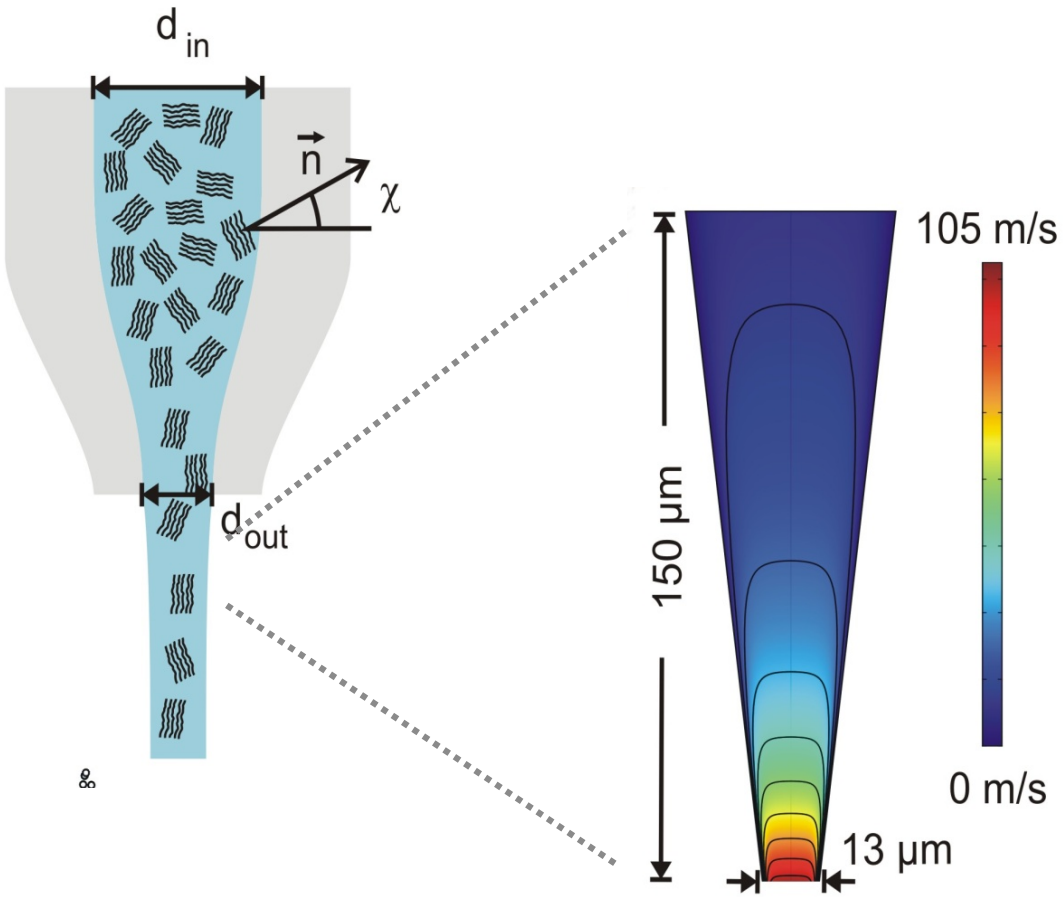


Microfluidic jet: SAXS of hydrated biomolecules



Priebe et al. New J. Phys. 2010

Vesicles in shear flow



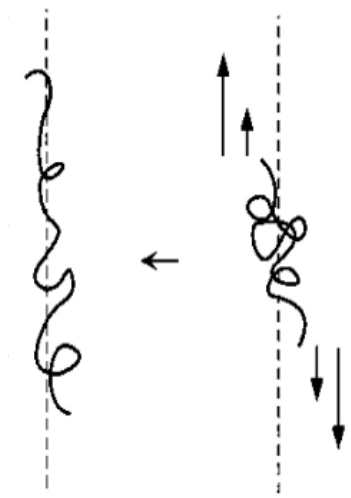
DOPC 100mg/ml

velocity profile in the nozzle

nozzle radius : $R \sim 10\mu m$

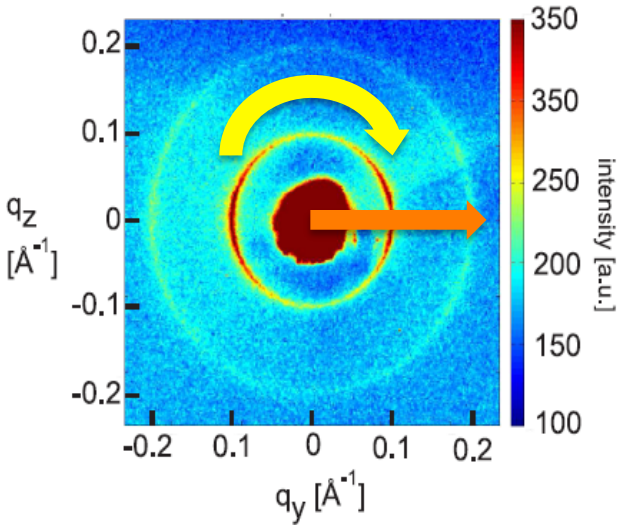
shear rate : $\dot{\gamma} = \frac{dv_z(r)}{dr} \sim 10^7 s^{-1}$

mean velocity : $\bar{v} = \frac{\dot{V}}{\pi R^2} \sim 10 \frac{m}{s}$

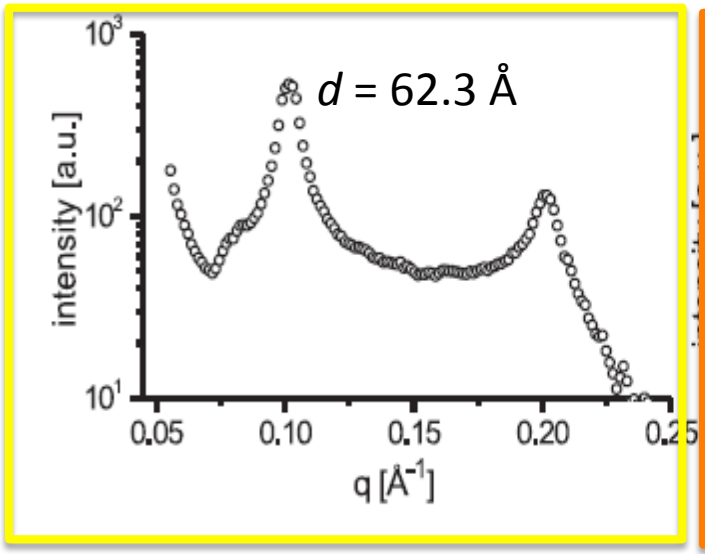


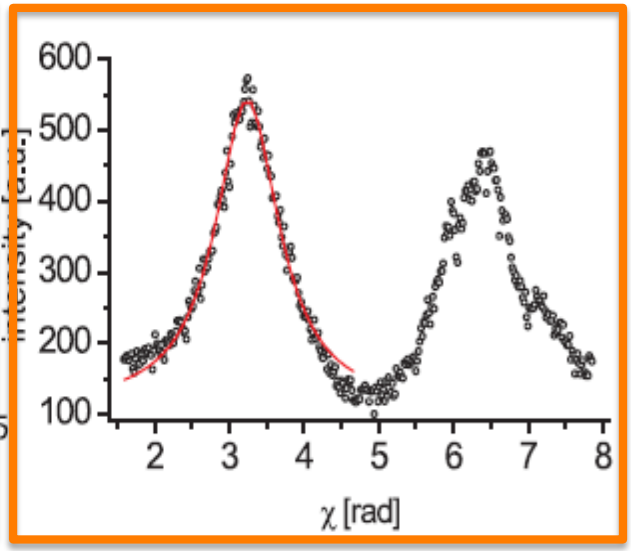
Priebe et al. New J. Phys. 2010

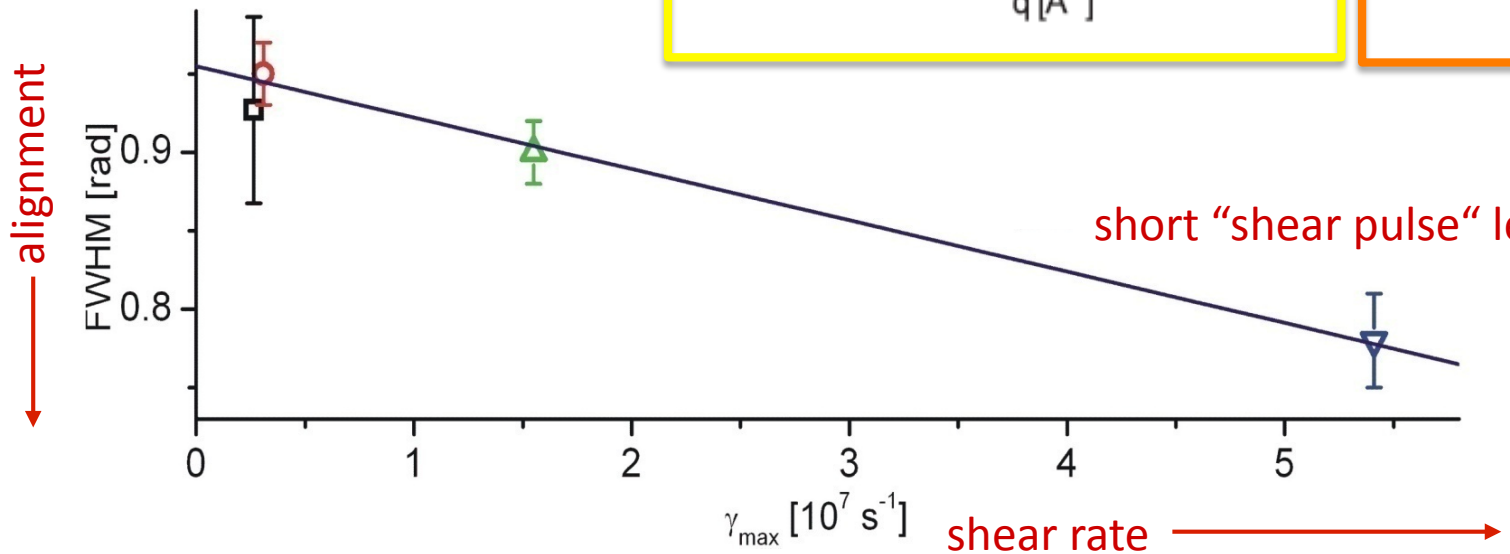
Microdiffraction in liquid jet



oriented lamellar phase.







short "shear pulse" leads to orientation

Priebe et al. New J. Phys. 2010