

MePhy Day: Scientific day Etienne Guyon  
Tuesday April 23<sup>rd</sup>, 2024, IPGG ESPCI, Paris, France

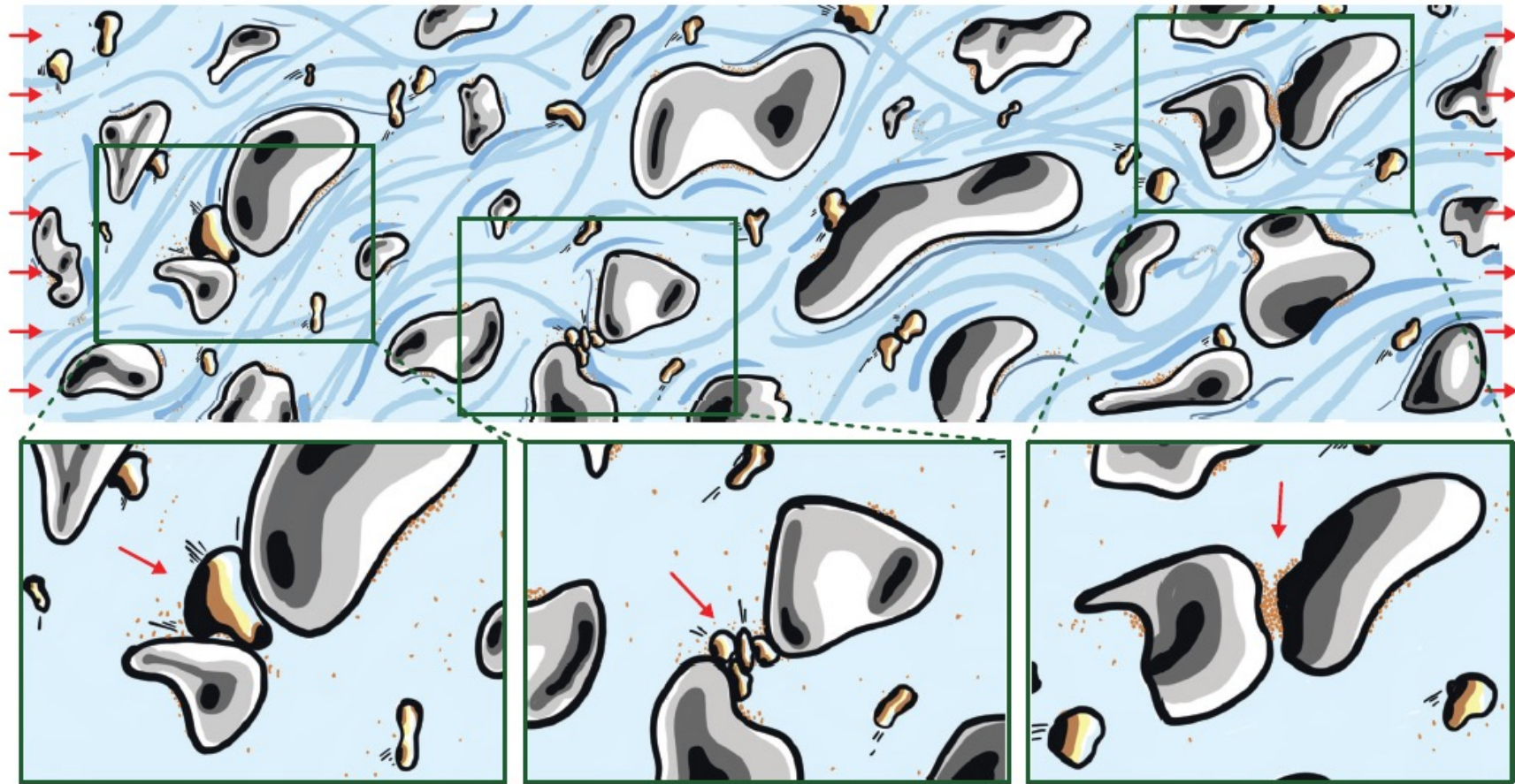
# Squeezing multiple soft particles into a constriction: Transition to clogging

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# Mechanisms of clogging



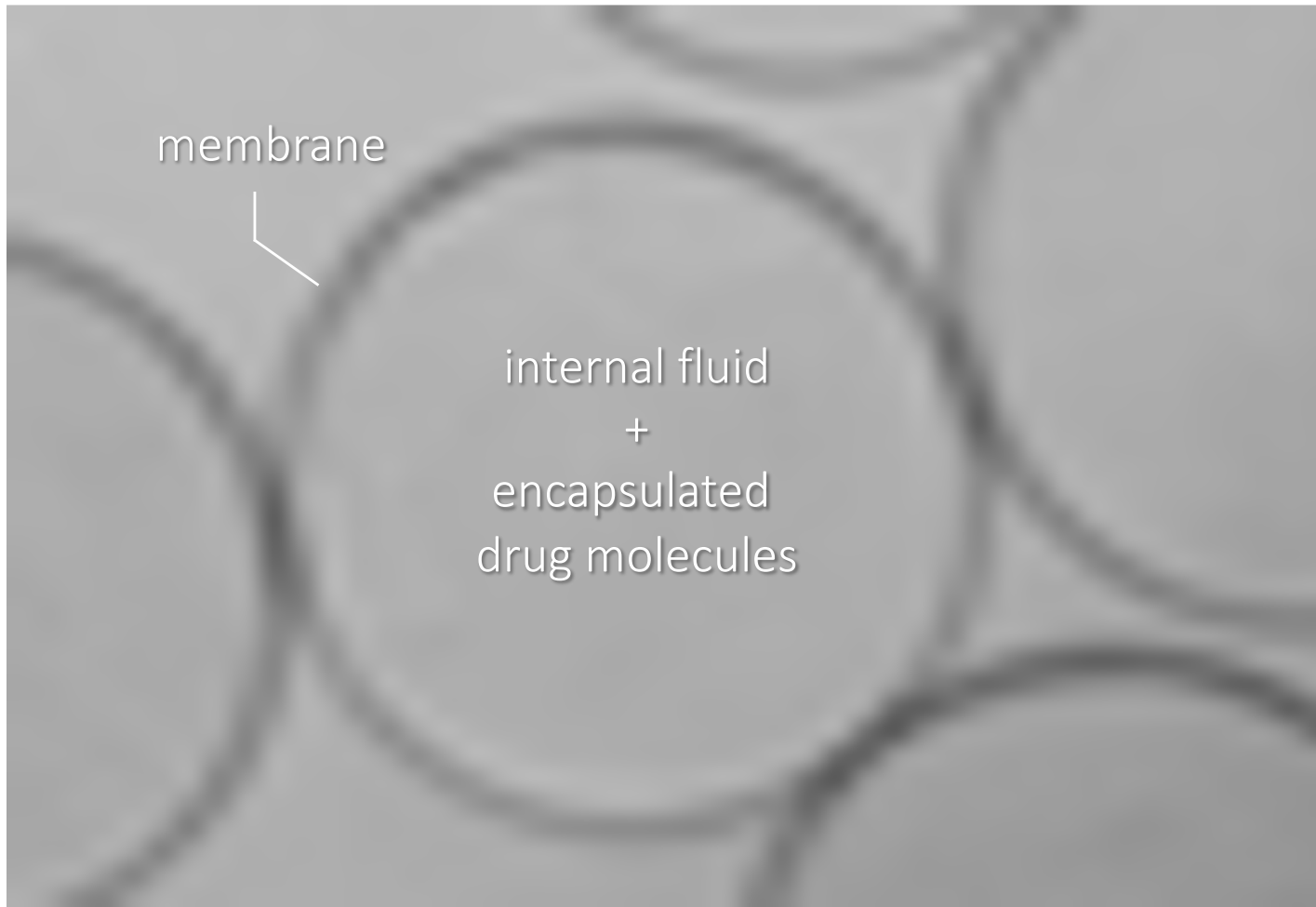
1 - Too big to fit

2 - Too crowded to pass

3 - Too sticky to flow

Clogging: The self-sabotage of suspensions,  
B. Dincău, E. Dresseire, A. Sauret,  
Physics Today 76 (2), 24–30 (2023)

# Soft particles: Microcapsules



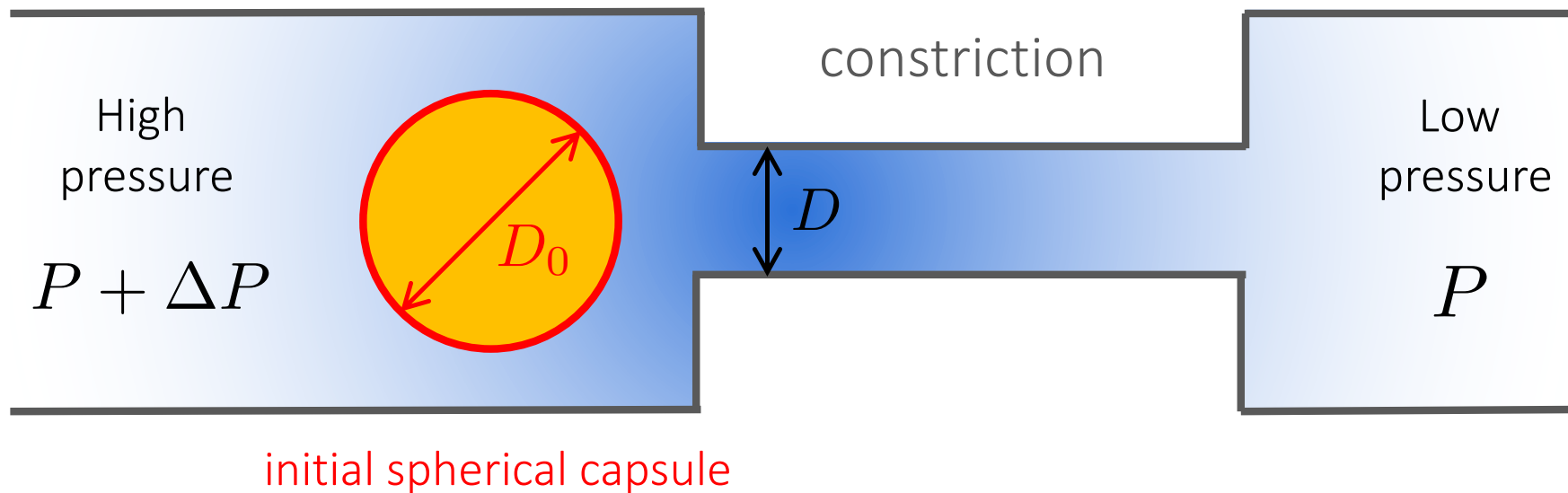
Capsules (closed polymeric membrane)

Squeezing a capsule  
into a constriction

# Experimental set-up

Le Goff, Kaoui, Salsac *et al.*, Soft Matter 13, 7644 (2017)

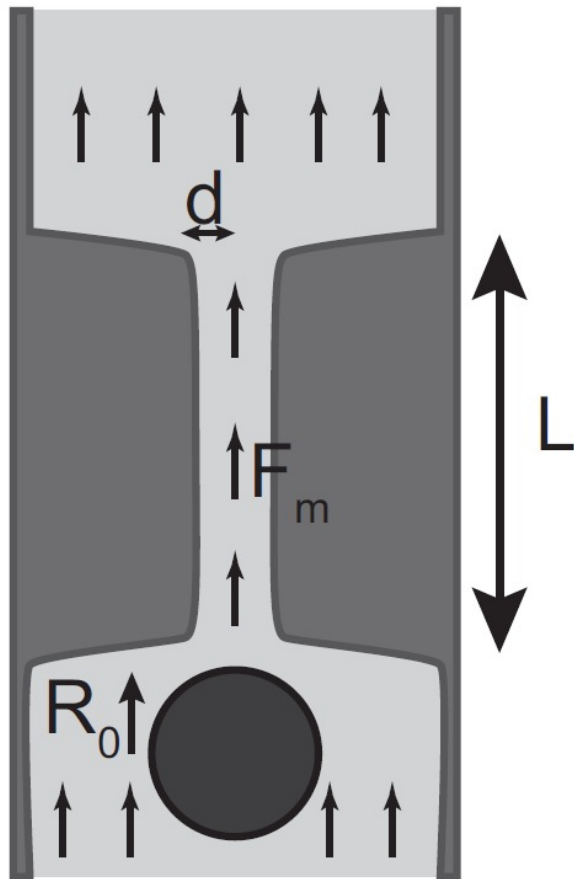
- bio-artificial capsules: alginate/albumin
- biological capsules: trout fish eggs



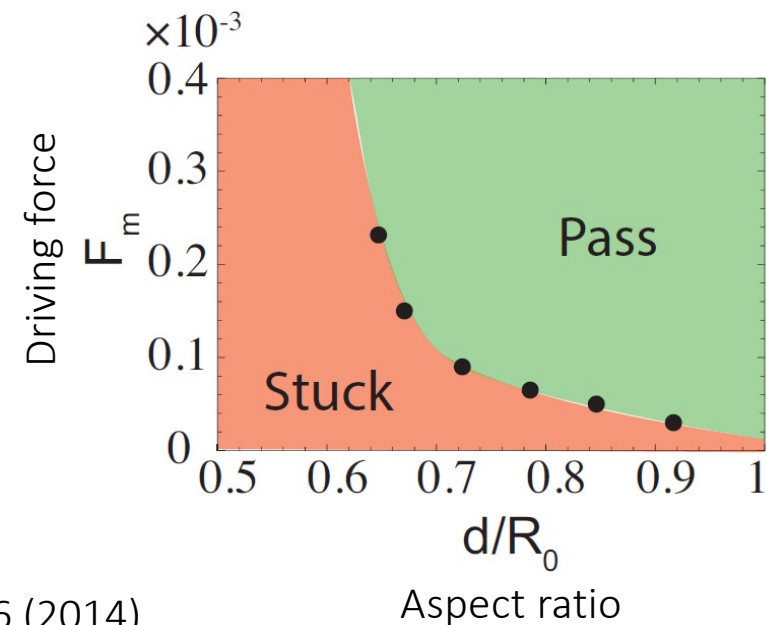
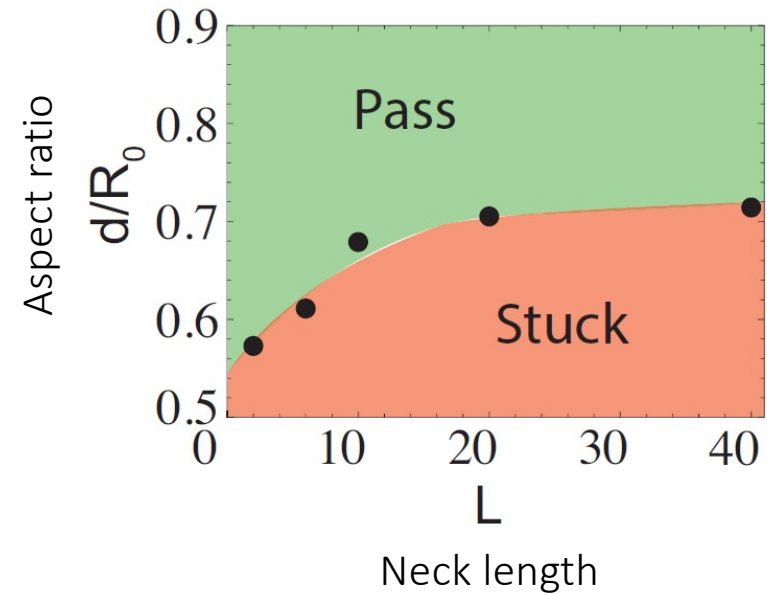
# Flow of a **single soft** particle through a narrow constriction

Fully 3D simulations

LBM, FEM, IBM

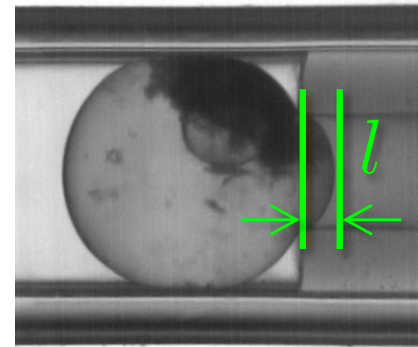
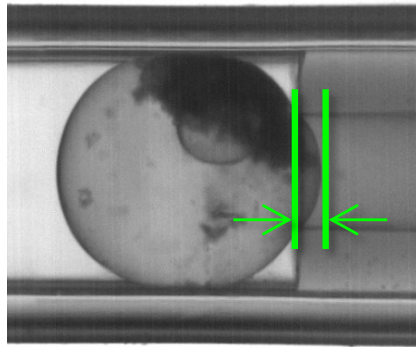
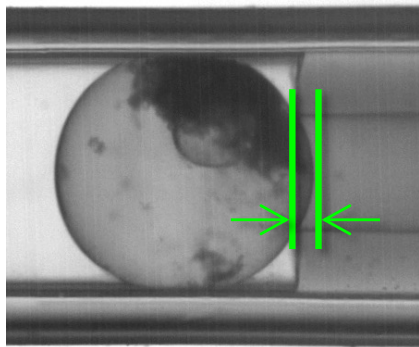


Aspect ratio:  $\frac{d}{R_0} < 1$



# Blocked state: Deformation

Le Goff, Kaoui, Salsac *et al.*, Soft Matter 13, 7644 (2017)

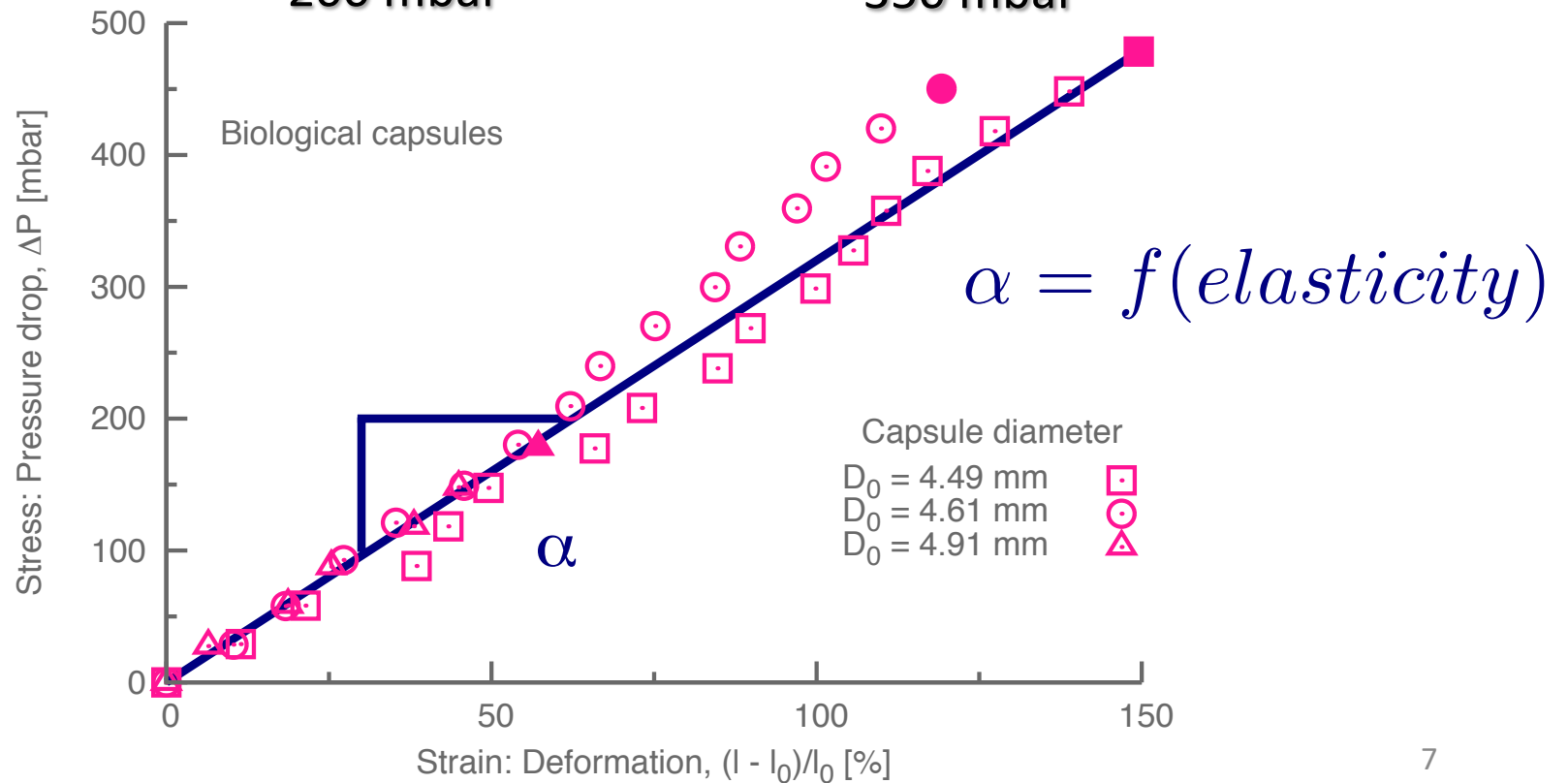


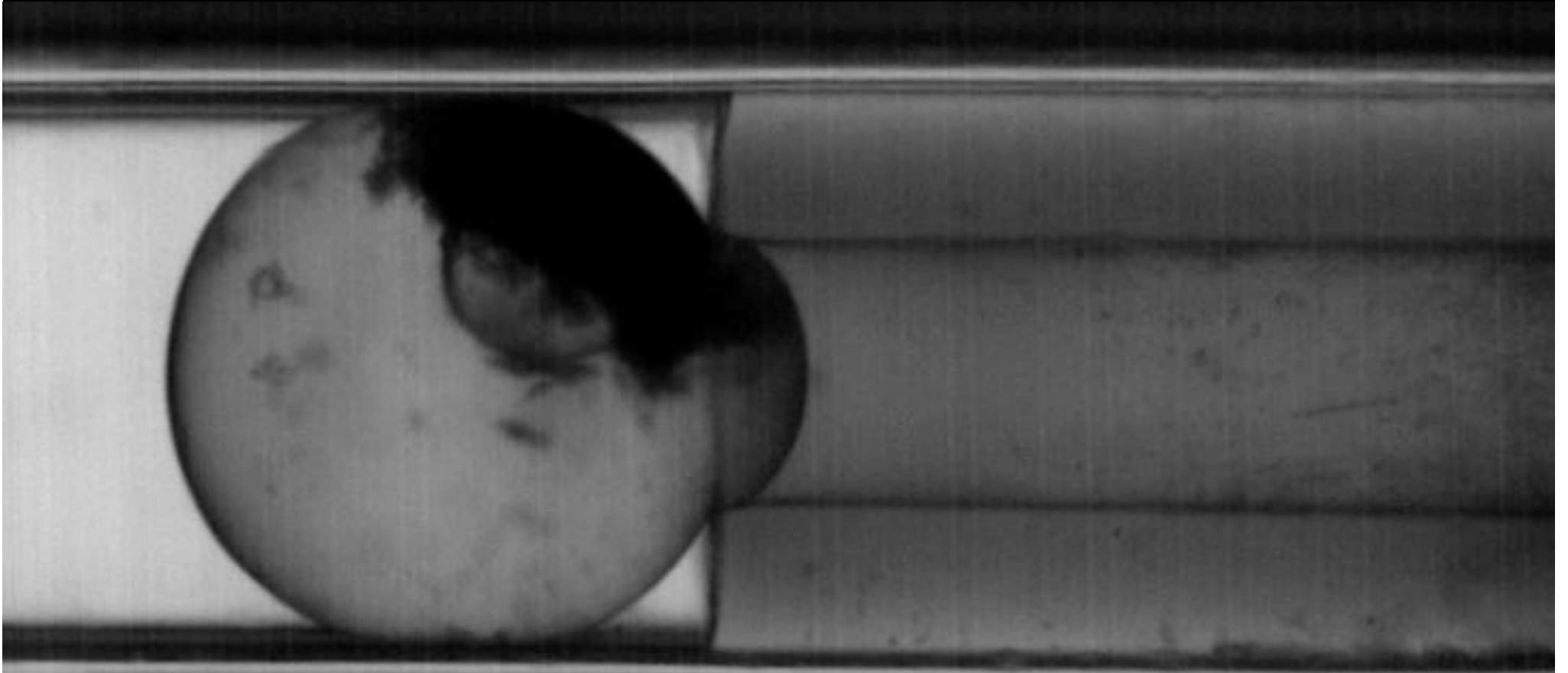
70 mbar

200 mbar

350 mbar

$\Delta P$

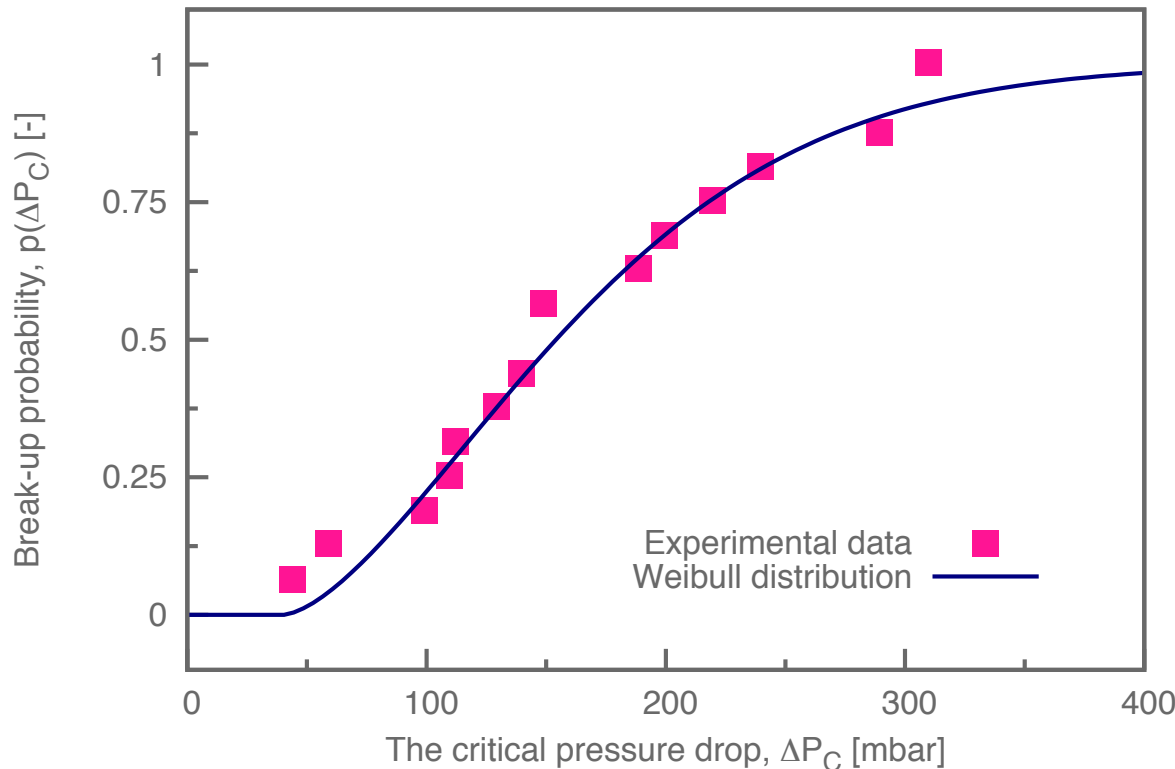
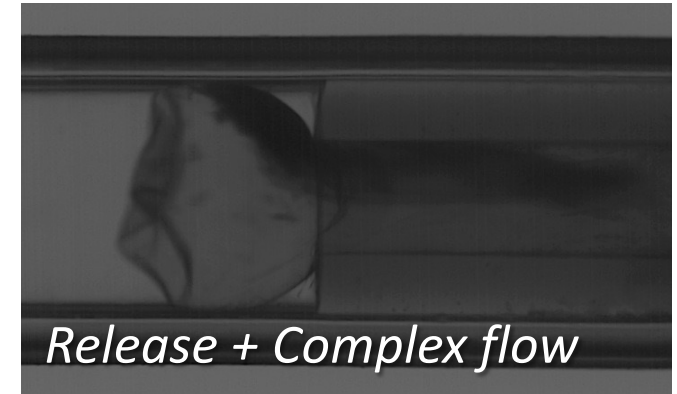
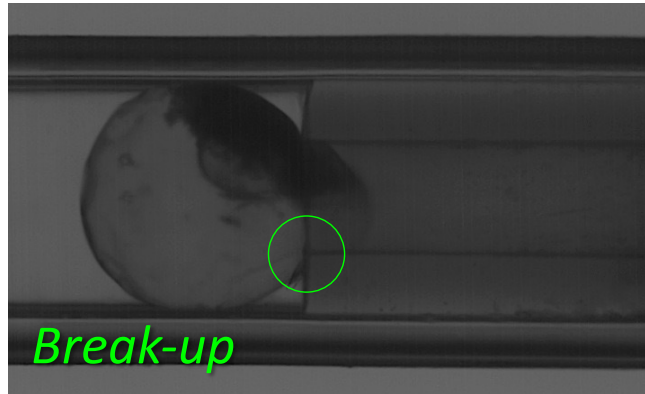






# Higher pressure: Transition to break-up

Le Goff, Kaoui, Salsac *et al.*, *Soft Matter* 13, 7644 (2017)



Roughness  
characterization

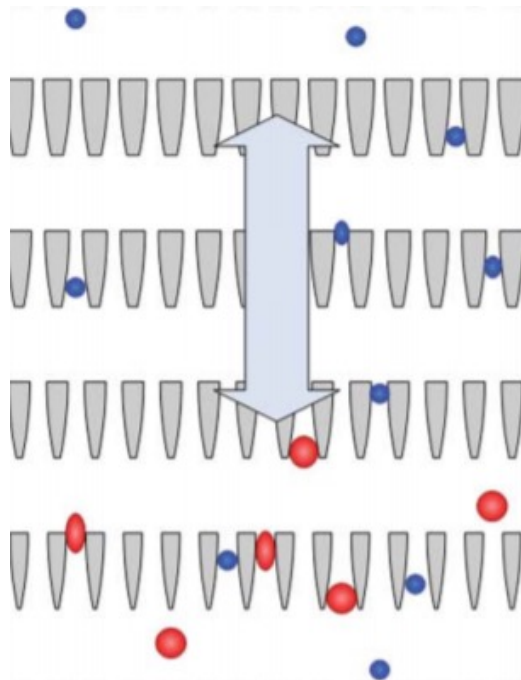
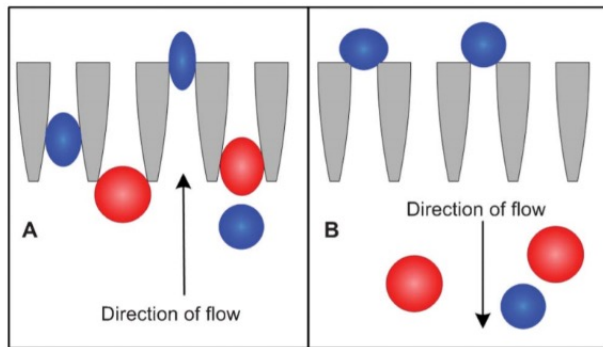
$$p(\Delta P_C) = 1 - \exp \left[ -\frac{(\Delta P_C - \Delta P_\mu)^m}{\Delta P_0} \right]$$

Weibull distribution

Break-up threshold:  
disordered media!

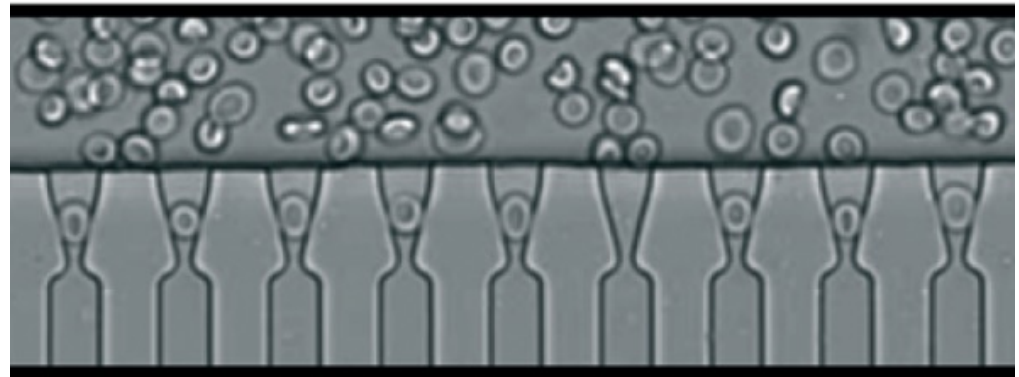
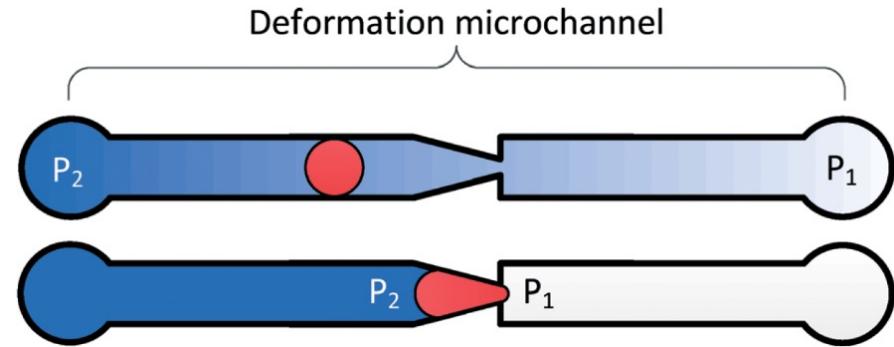
Squeezing multiple capsules  
into a constriction

## Sorting



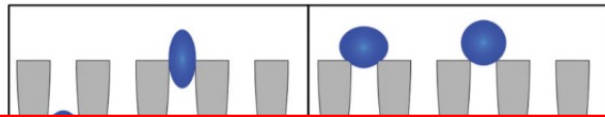
Ma *et al.*, Lab on a Chip (2012)

## Mechanical characterization



Myrand-Lapierre *et al.*, Lab on a Chip (2015)

Sorting

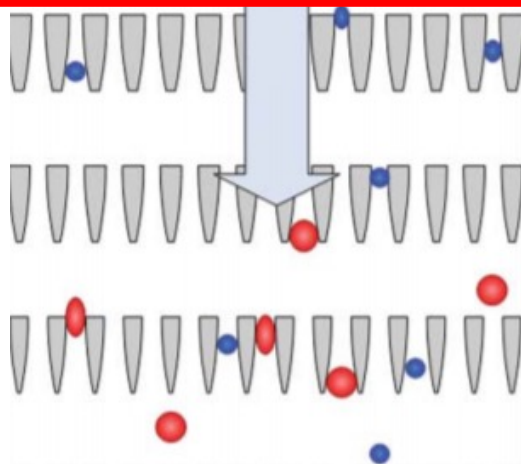


Mechanical characterization

Deformation microchannel



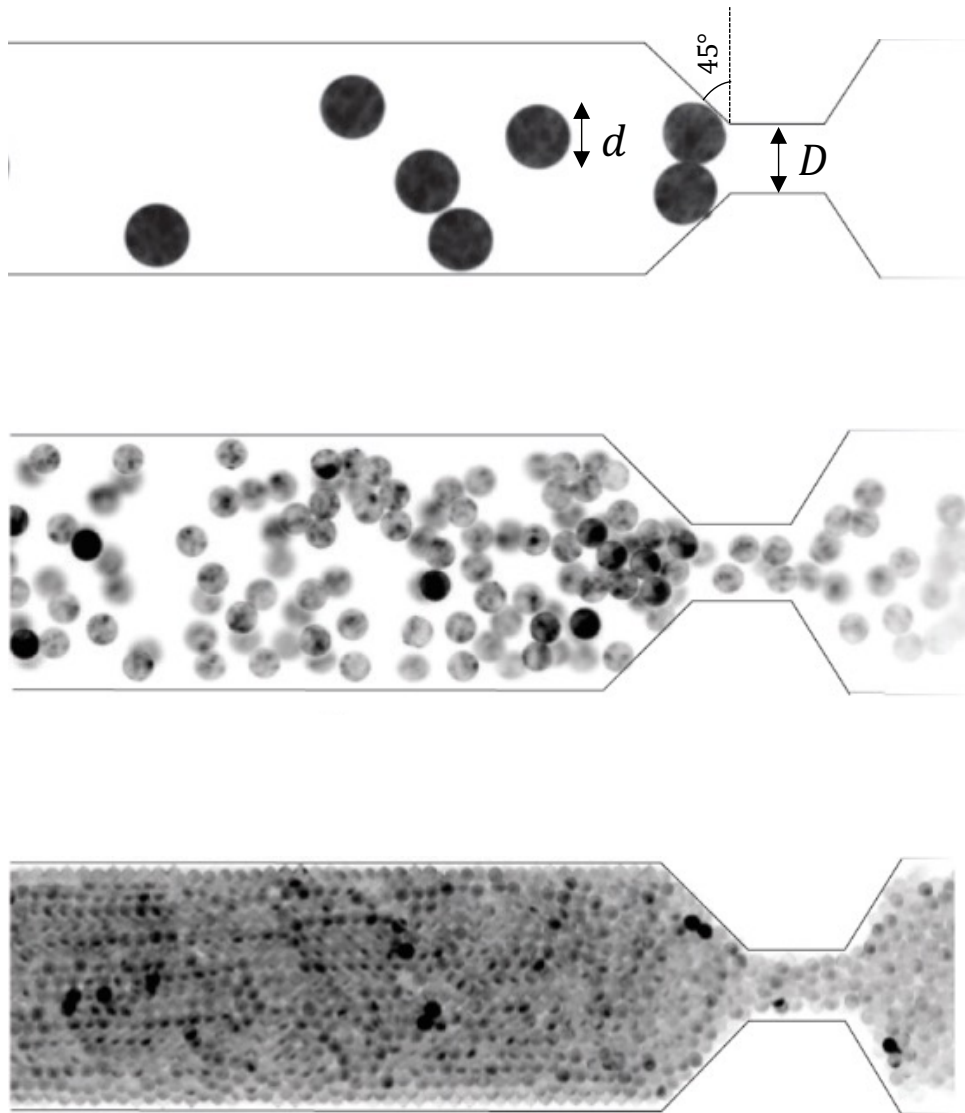
Drawback:  
clogs formation



Ma *et al.*, Lab on a Chip (2012)

Myrand-Lapierre *et al.*, Lab on a Chip (2015)

# Flow of **multiple rigid** particles through a narrow constriction



The confinement  $D/d$  determines the flow regime

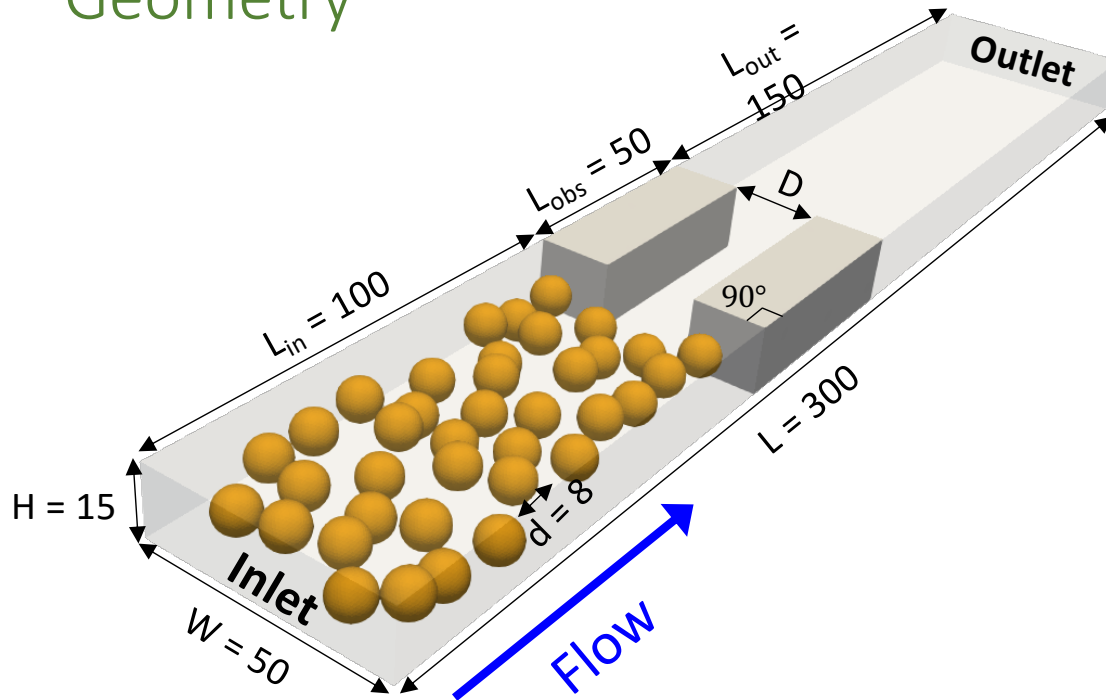
$D/d < 3$ : randomly-formed clogs

●  $D/d \approx 3$ : transient clogs

$D/d > 3$ : no clog

# Present study: flow of **multiple soft** particles through a narrow constriction

## Geometry



## Key parameters

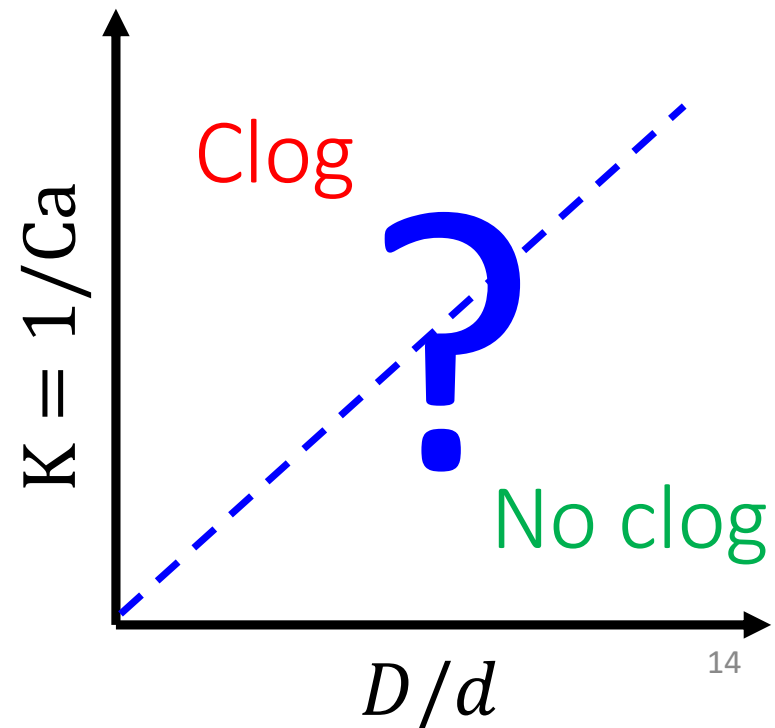
Aspect ratio:  $D/d > 1$

Particles deformability:  $Ca = \frac{\mu \frac{d}{2} \dot{\gamma}}{k_s}$

Fully 3D simulations

LBM, FEM, IBM

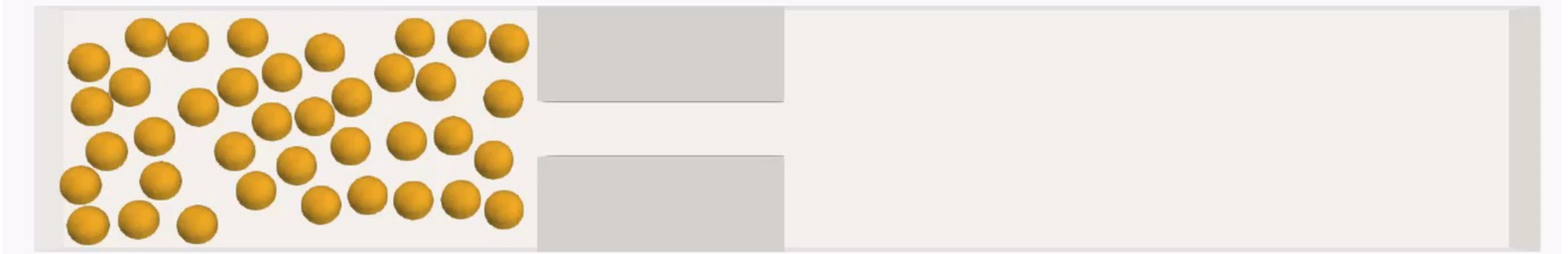
States diagram



# Effect of confinement

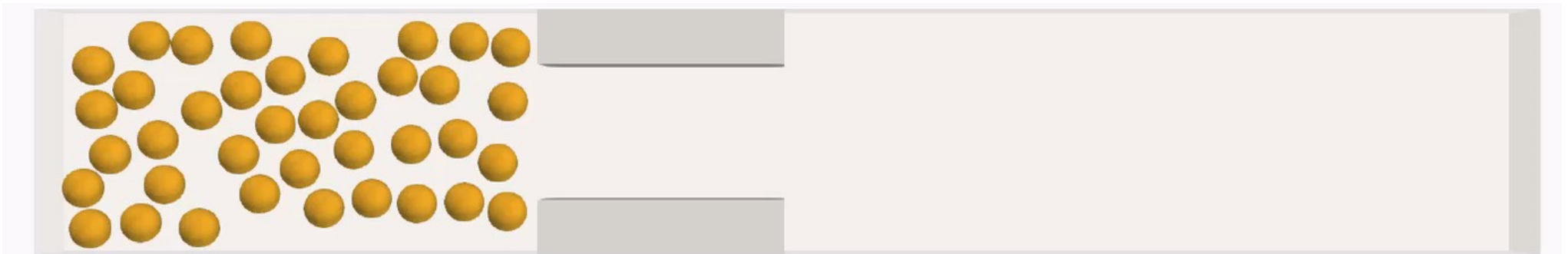
Bielinski, Aouane, Harting, Kaoui, Physical Review E 104, 065101 (2021)

$D/d = 1.25$ ,  $Ca = 0.001$  (low deformability)



Clog

$D/d = 3.25$ ,  $Ca = 0.001$  (low deformability)



No clog

# Effect of deformability

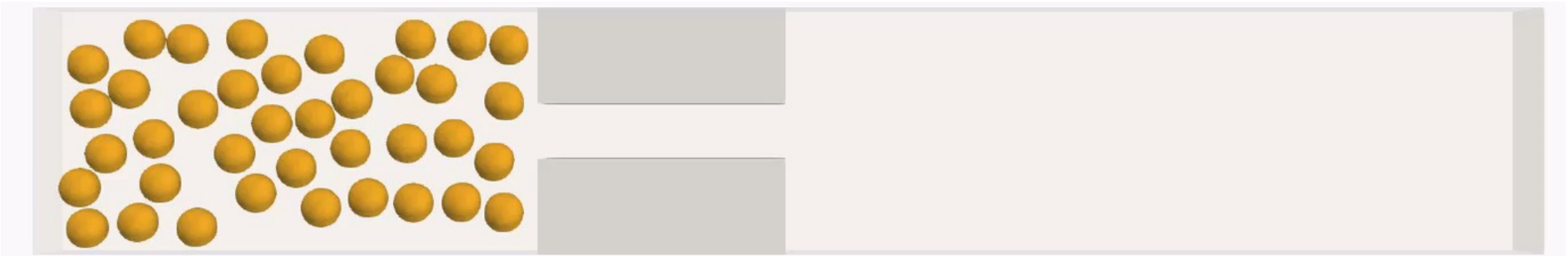
Bielinski, Aouane, Harting, Kaoui, Physical Review E 104, 065101 (2021)

$D/d = 1.25$ ,  $Ca = 0.001$  (low deformability)



Clog

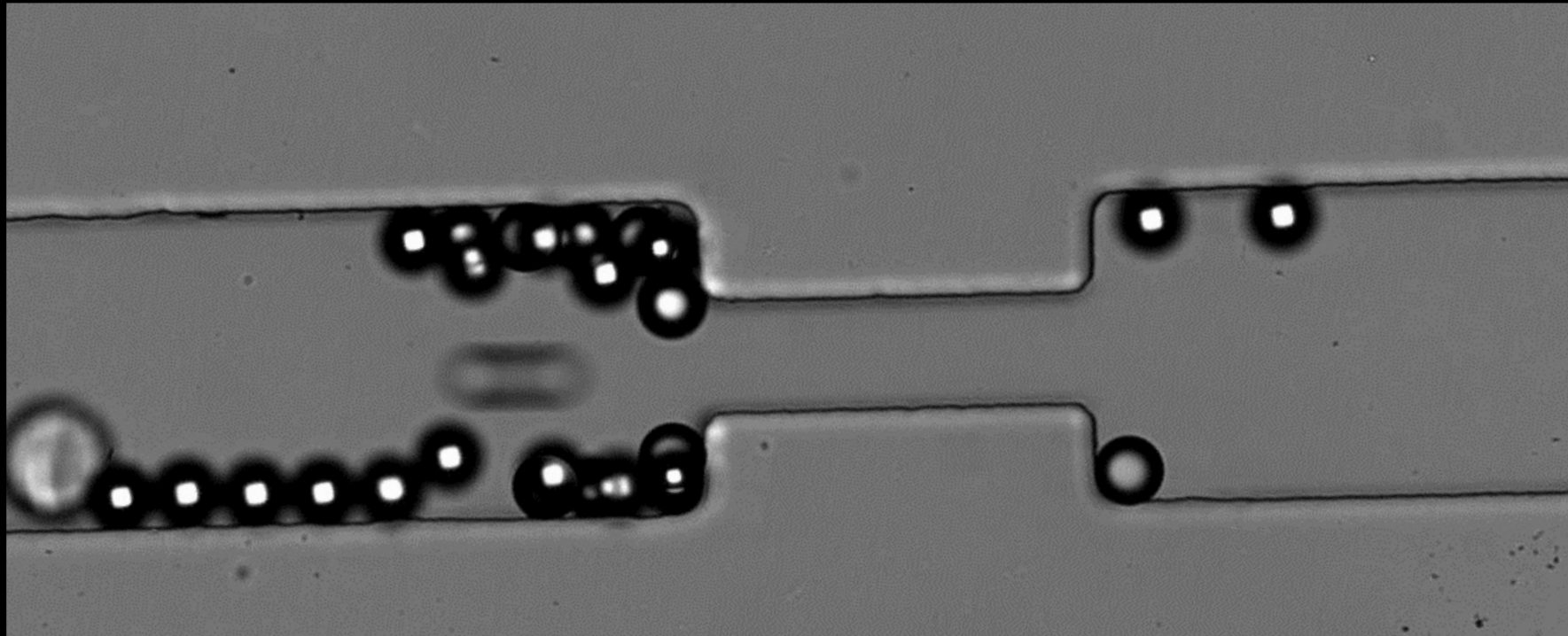
$D/d = 1.25$ ,  $Ca = 0.1$  (high deformability)



No clog

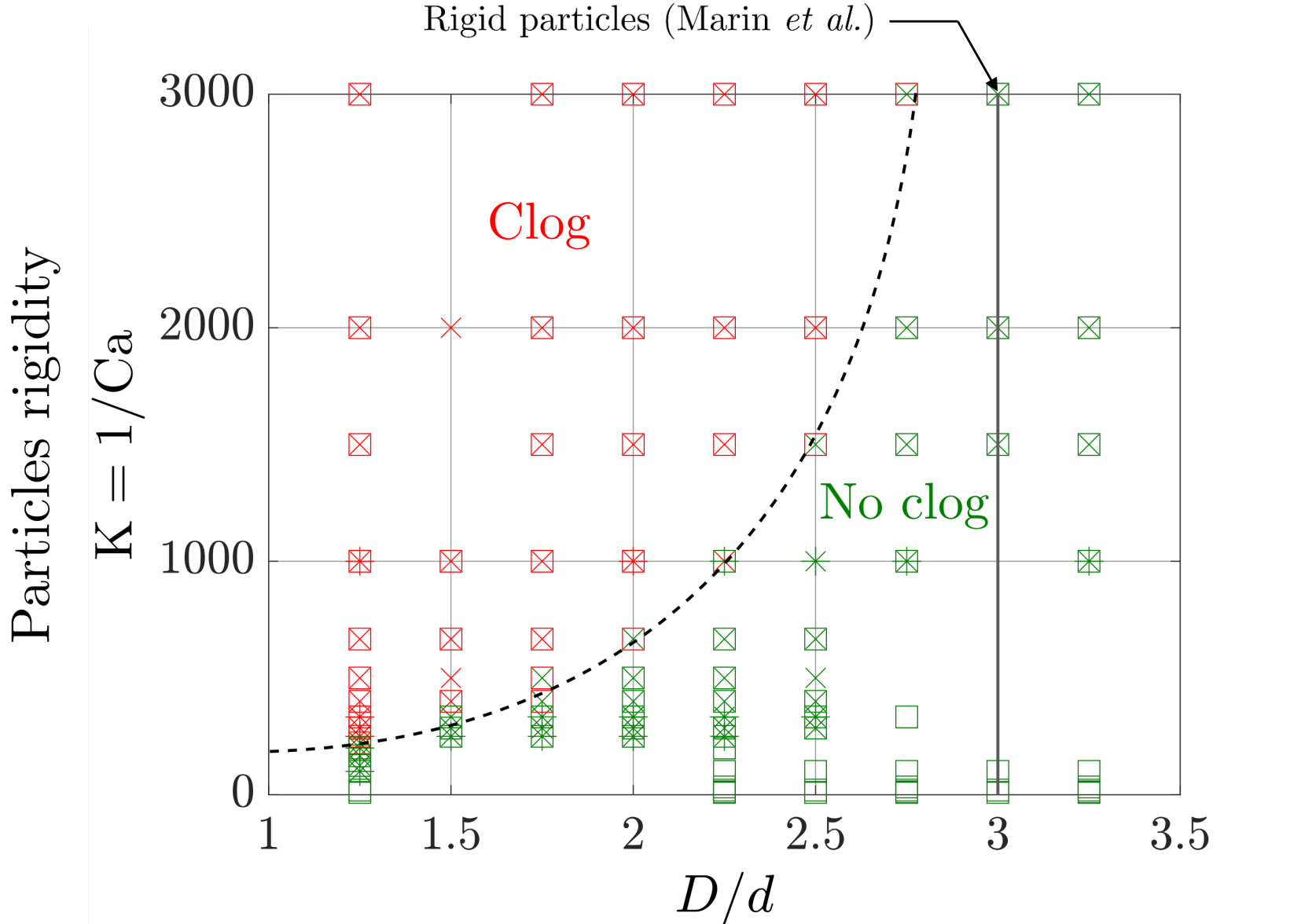


Particle size = 34  $\mu\text{m}$   
Constriction width = 50  $\mu\text{m}$   
Particle size to constriction width ratio = 1.47  
Pressure = 500 mbar  
Video slowed down 66 time



E. Decombis, MEng Internship Project (2020)

# States diagram

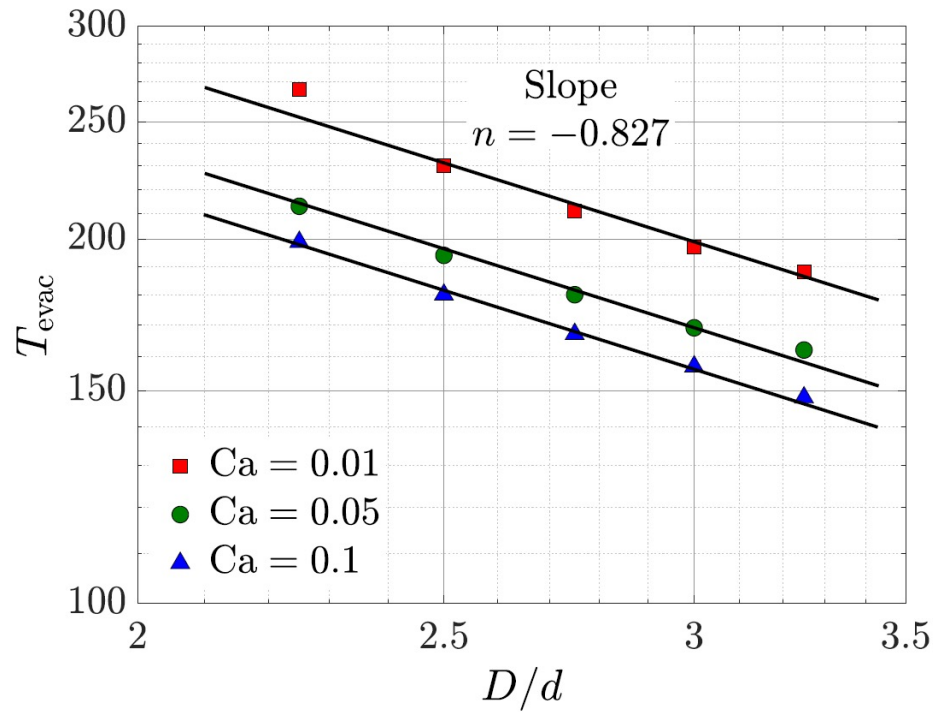


Bielinski, Aouane, Harting, Kaoui,  
Physical Review E 104, 065101 (2021)

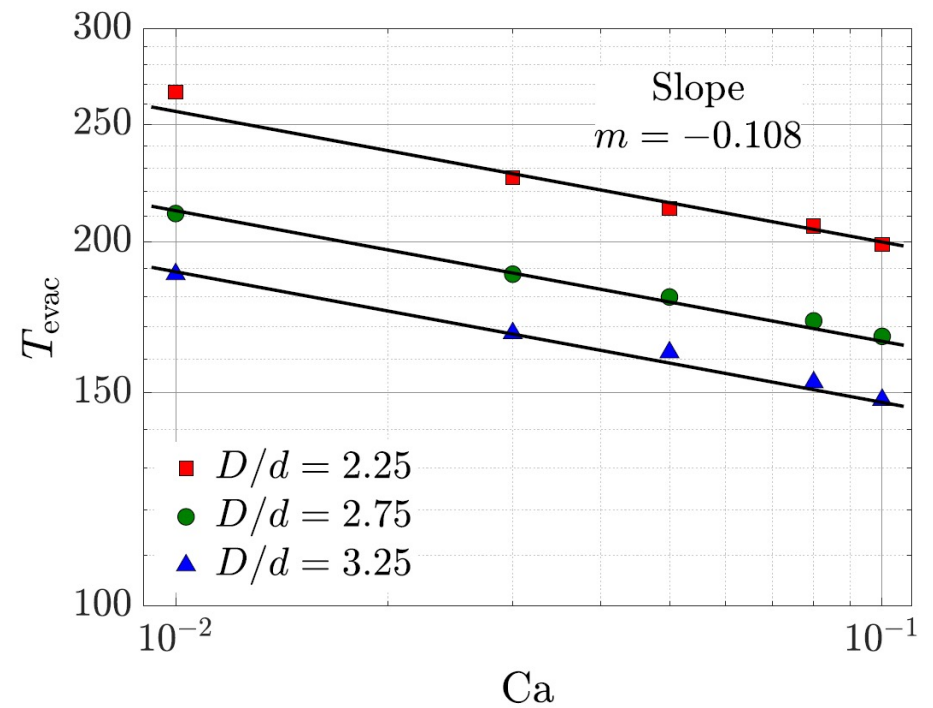
# Evacuation times

Bielinski, Aouane, Harting, Kaoui, Physical Review E 104, 065101 (2021)

### Effect of aperture



$$T_{\text{evac}} \propto \left(\frac{D}{d}\right)^{-0.827}$$

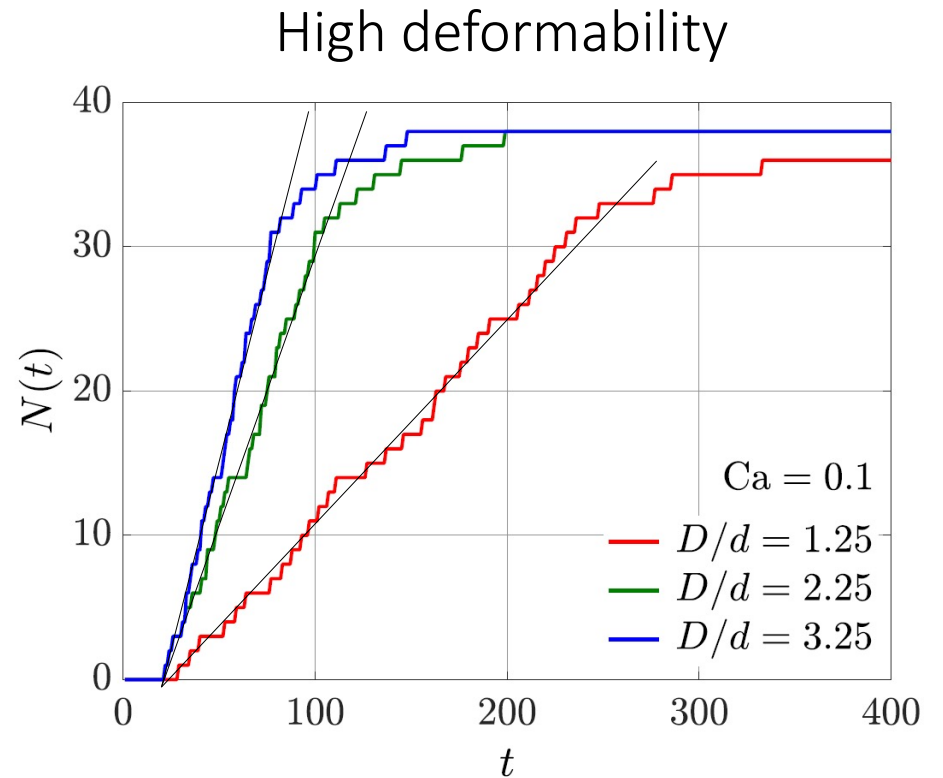
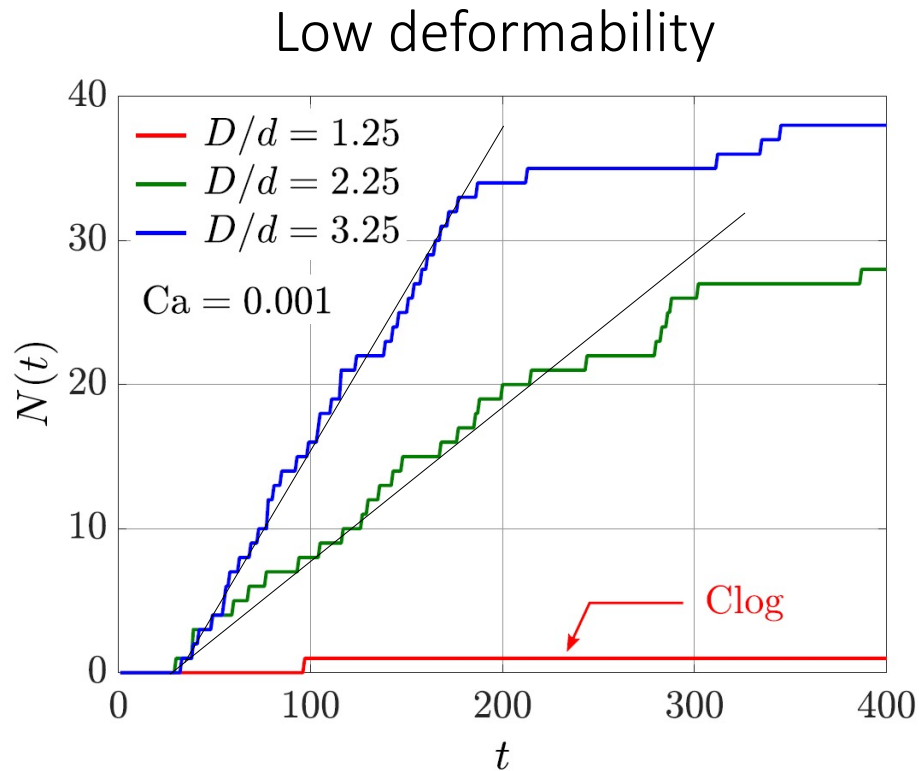


$$T_{\text{evac}} \propto \text{Ca}^{-0.108}$$

New : Effect of the deformability

# Dynamics of particles passage: Numerical data

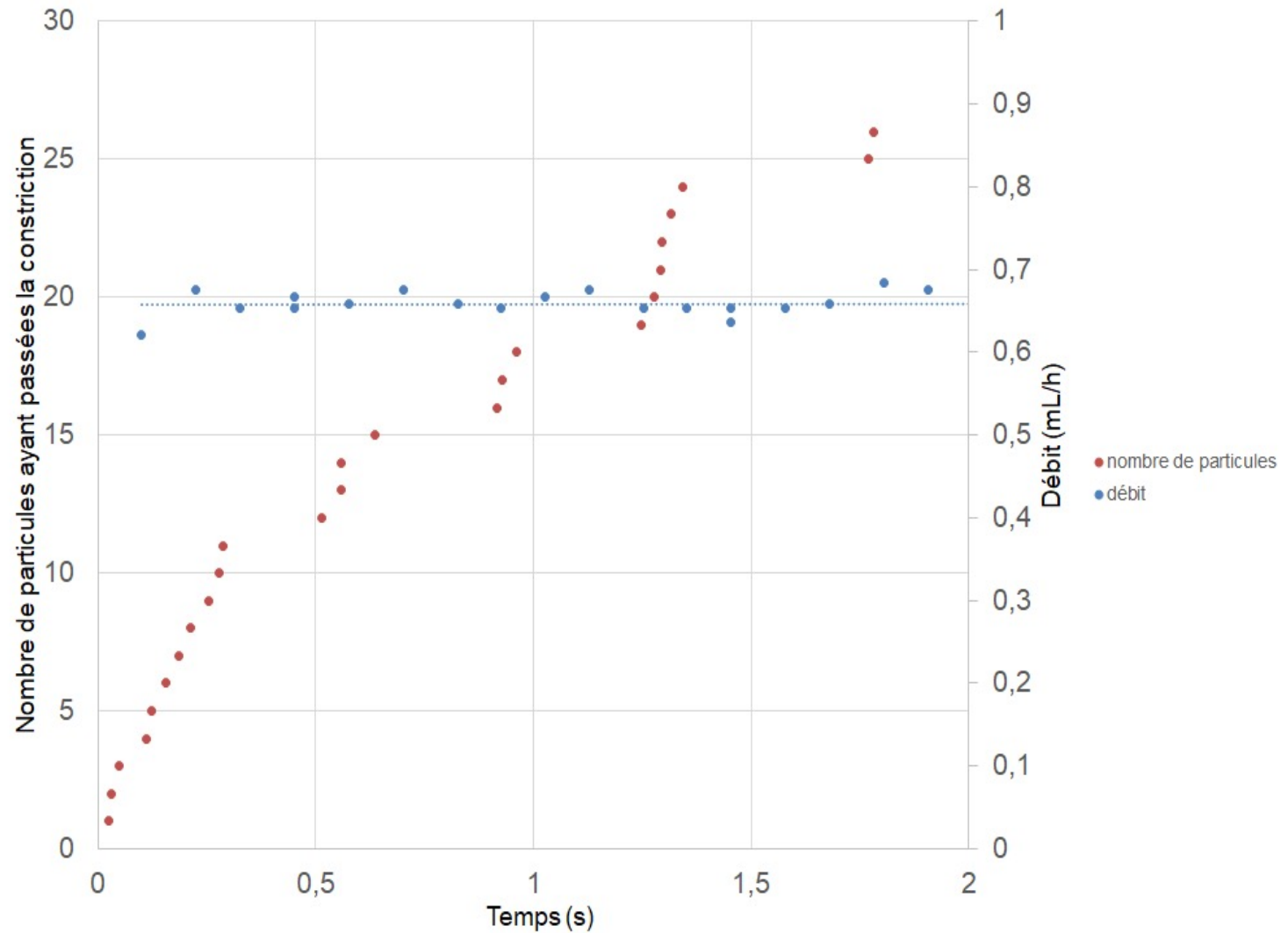
Bielinski, Aouane, Harting, Kaoui, Physical Review E 104, 065101 (2021)



Higher deformability and wider neck: higher flow rate of particles

# Dynamics of particles passage: Experimental data

flow clogs – unclogs periodically: intermittency



# Conclusions

- This study complements previous studies dealing with either a single deformable particle, or multiple rigid particles,
- Effects of confinement and particles deformability on the transition to clogging are investigated and reported in a states diagram,
- The evacuation time decreases nonlinearly when increasing the aperture and the particles deformability,
- The effect of the number of particles and channel geometry are left for future works.

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