Viscous pumping of liquids with cavitation bubbles

Viskoses Pumpen von Flüssigkeiten
mit Kavitationsblasen

Robin Schädel, Hendrik Reese, Fabian Reuter, Claus-Dieter Ohl

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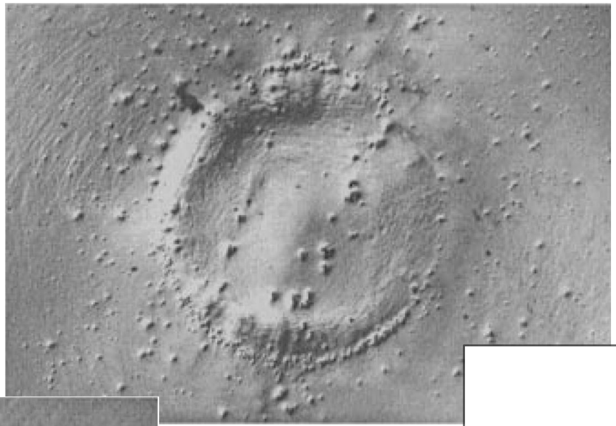
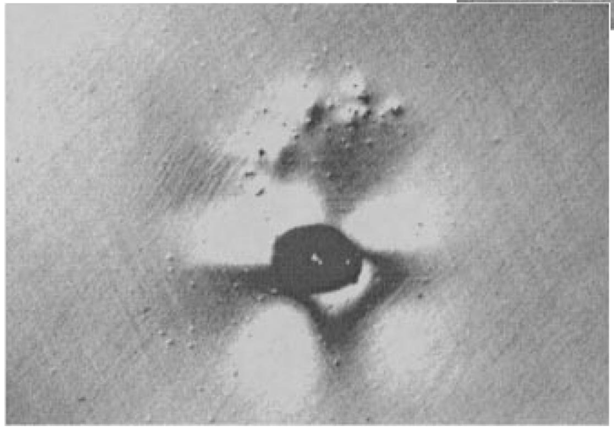
OTTO VON GUERICKE
UNIVERSITÄT
MAGDEBURG
NAT
FAKULTÄT FÜR
NATURWISSENSCHAFTEN

Motivation

Result: Erosion

R_{max} = 1.45 mm
Frame width = 2.6 mm

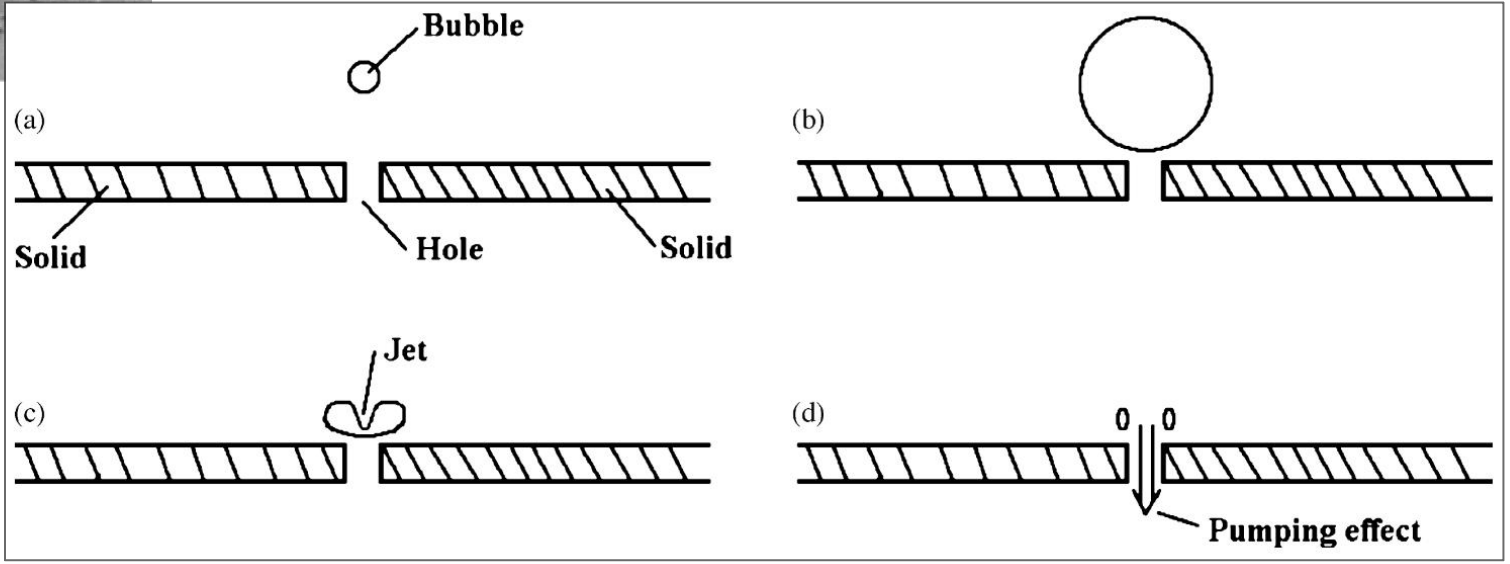




Philipp, A., & Lauterborn, W. (1998). Cavitation erosion by single laser-produced bubbles. Journal of Fluid Mechanics, 361, 75–116.

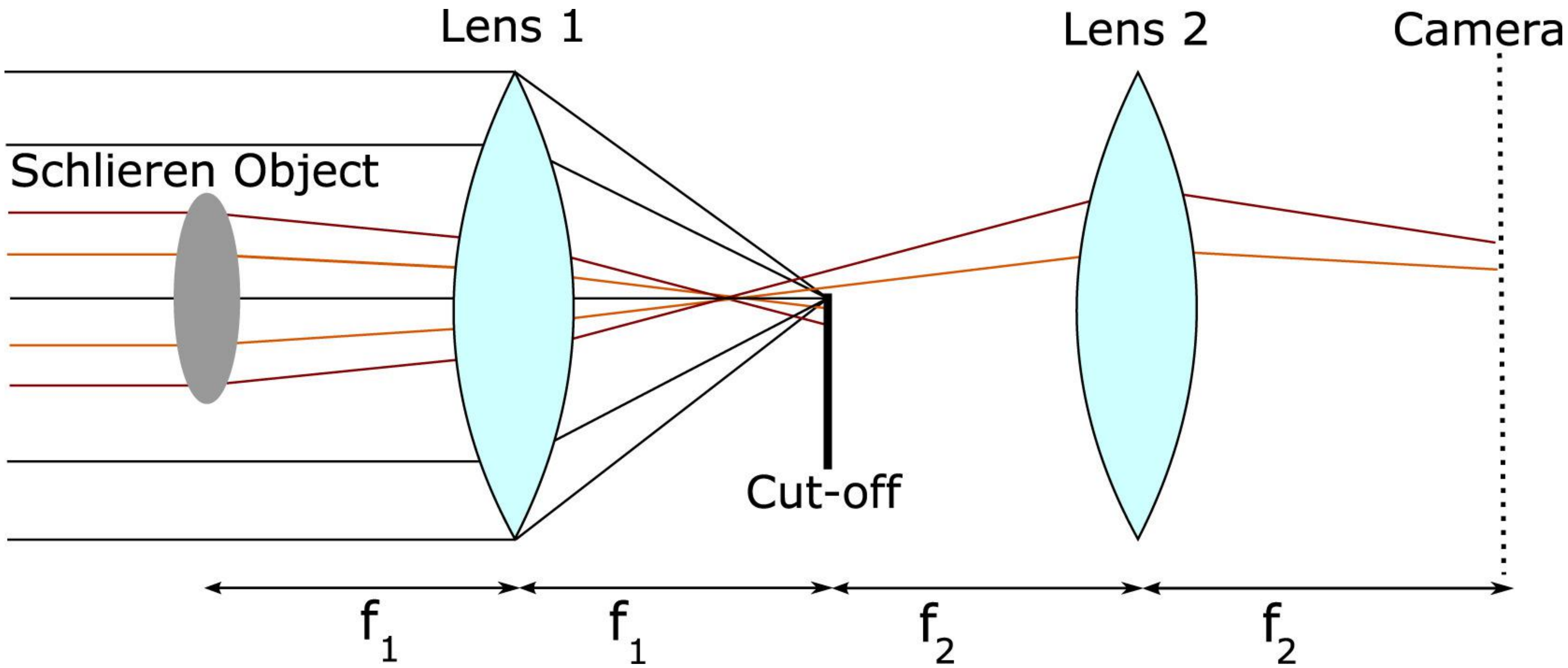
Useful application?
Ultrasonic cleaning,
Mixing of fluids e.g. emulsion, …

→ Microfluidic pumping



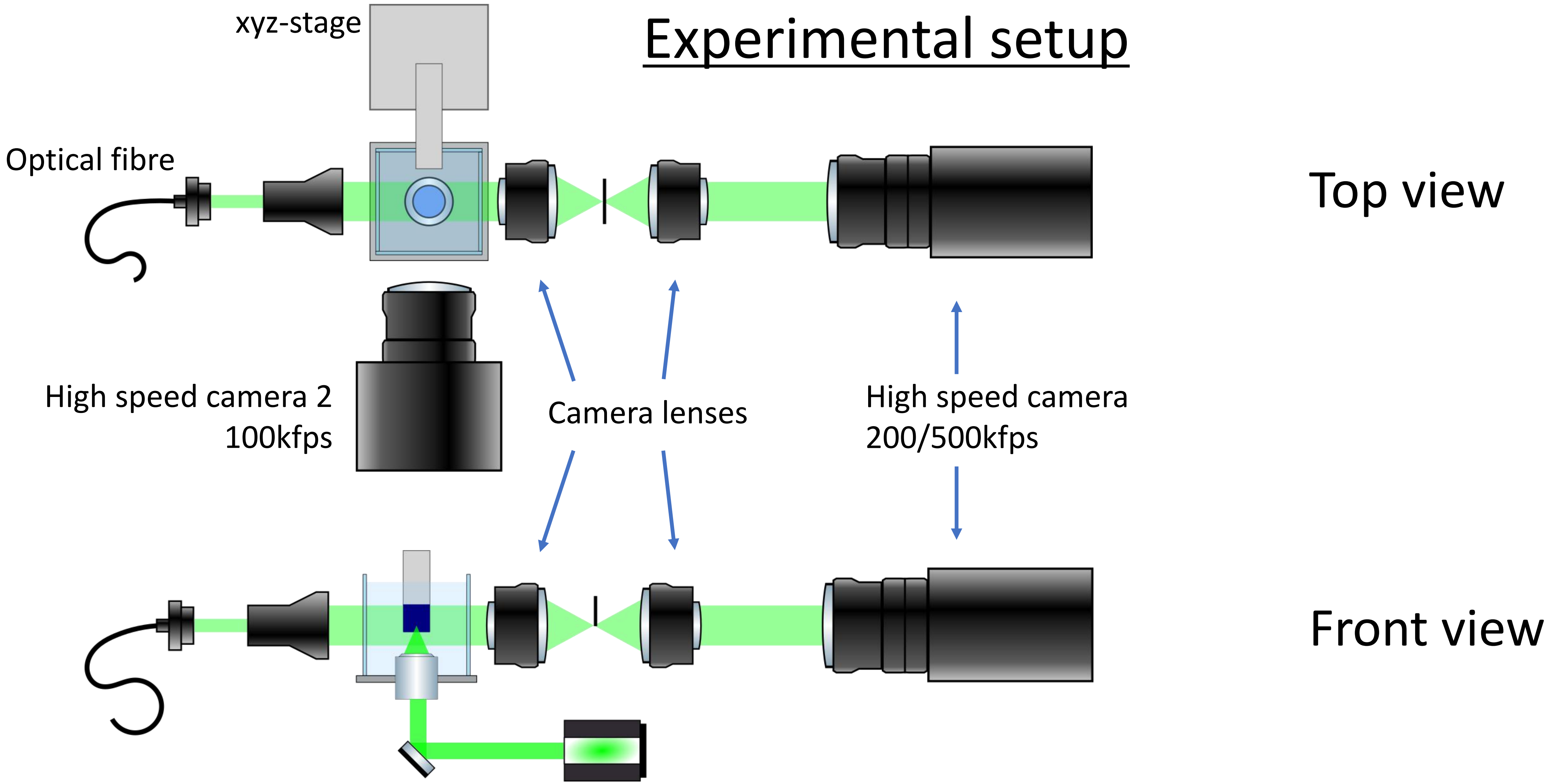
Lew et al. (2007). A collapsing bubble-induced micropump: An experimental study. Sensors and Actuators, A: Physical.

Schlieren basics



Bachmann et al. (2018). Schlieren imaging for the determination of the radius of an excited rubidium column. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 909, 387–390.

Experimental setup



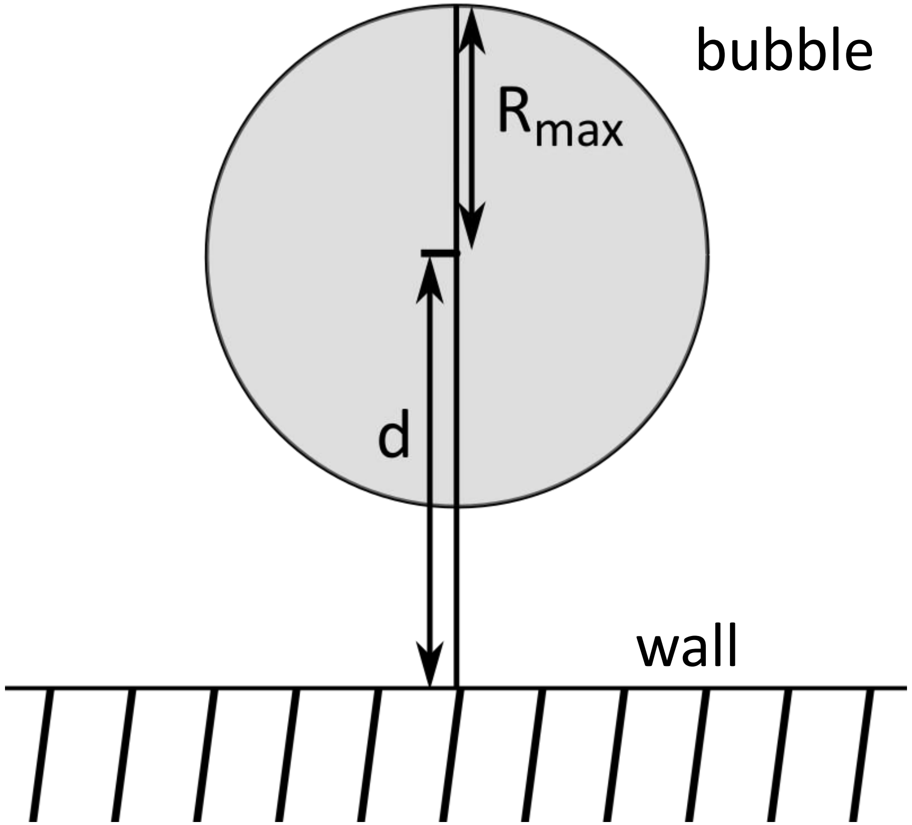
Important parameters

Non-dimensional stand-off parameter

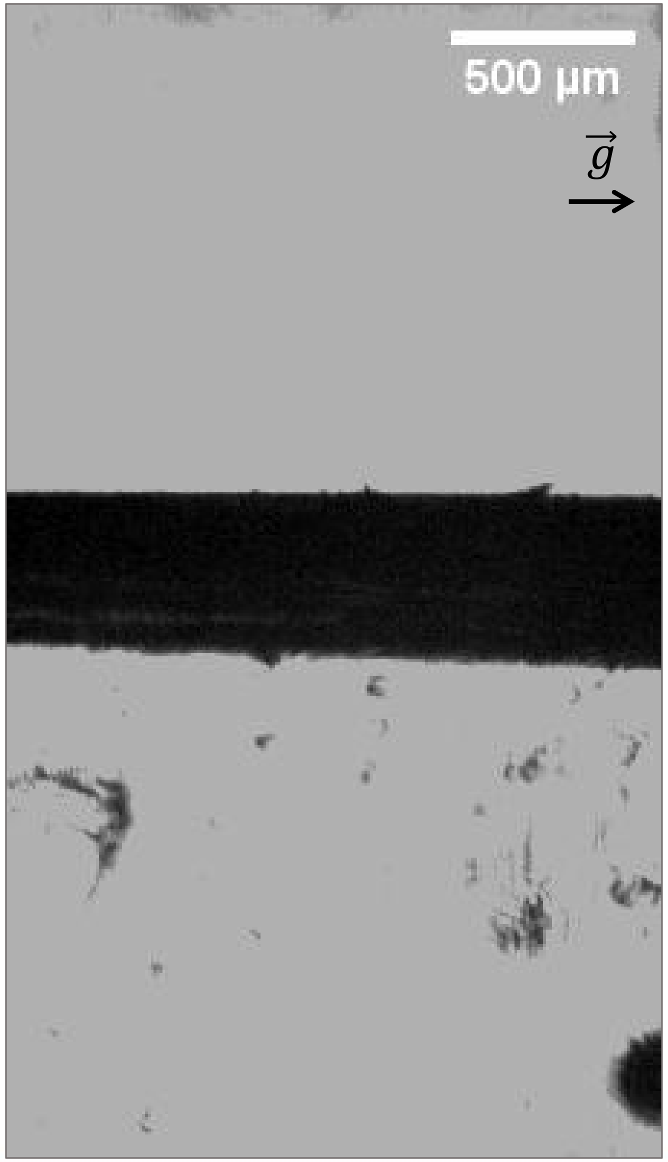
$$\gamma = \frac{d}{R_{max}}$$

R_{max} – maximum bubble radius

d – distance from wall



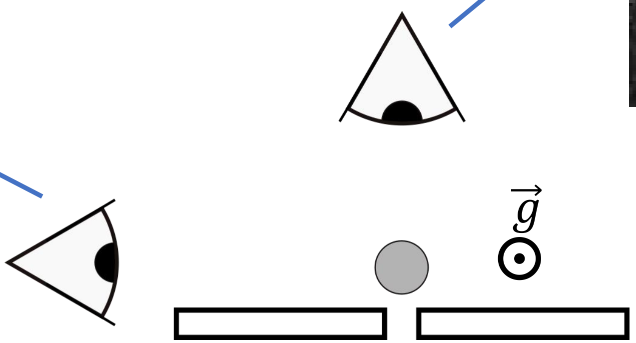
Results



Side view
@ 500kfps

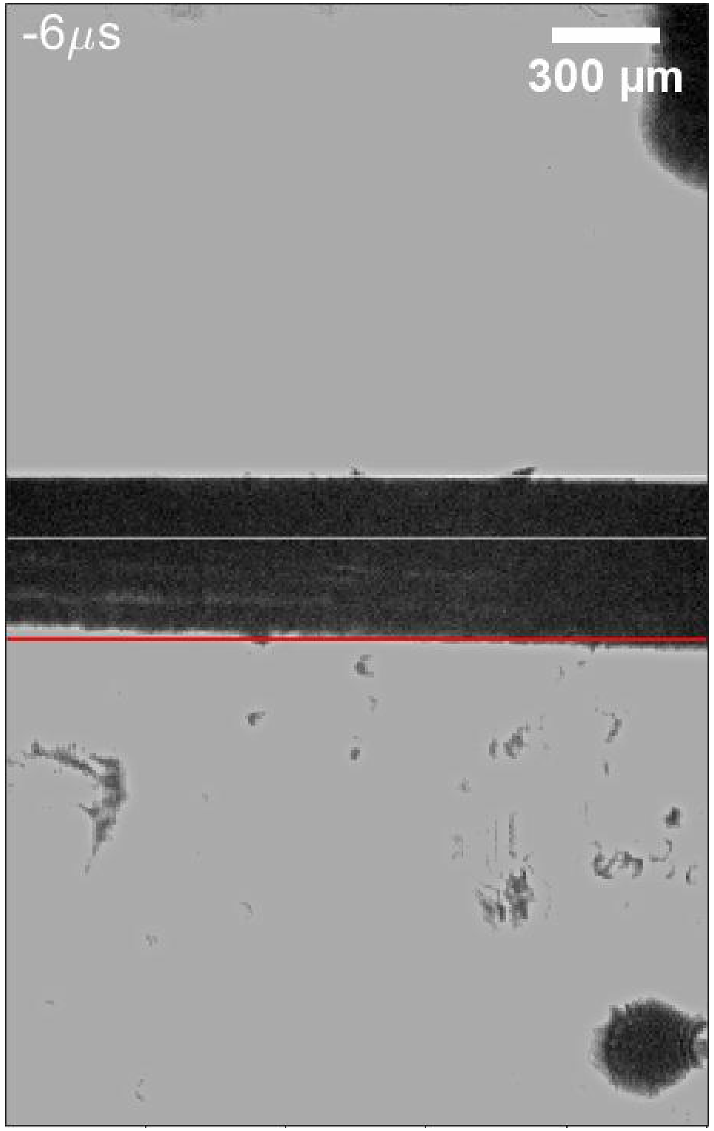
← DI-water

← NaCl solution

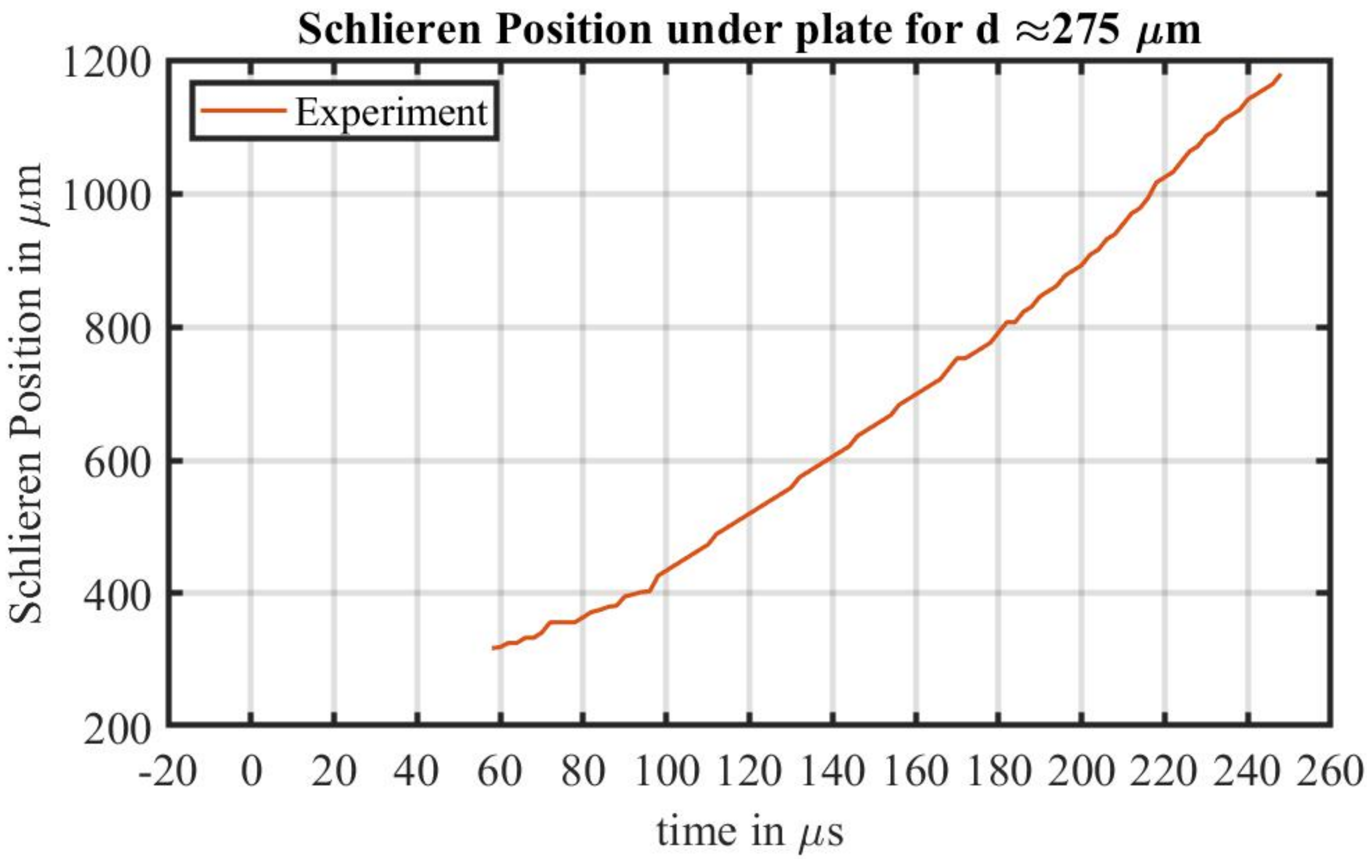


Front view @ 100kfps

$\gamma = 0.6$
T_L = 88 µs
R_{max} = 458 µm

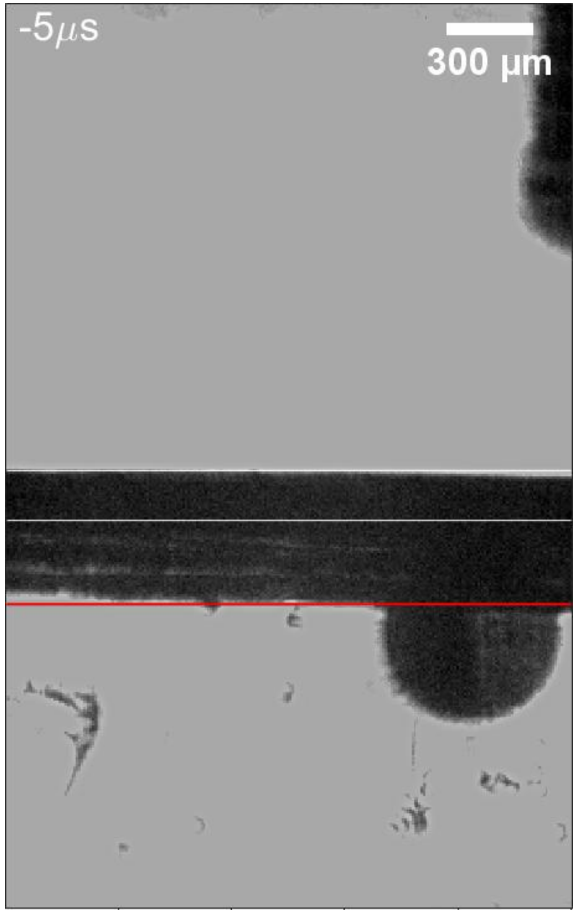


Tracking of Schlieren tip position

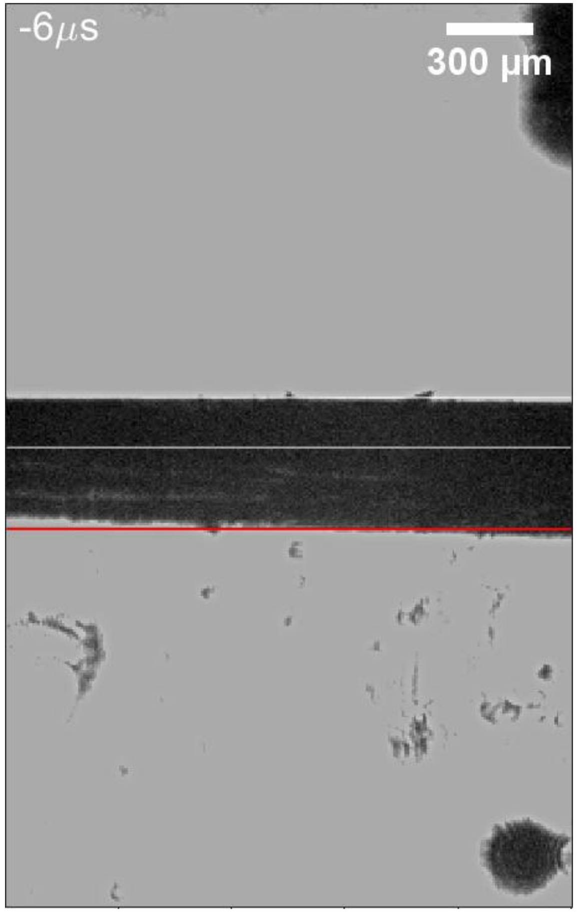


Identified regions

Second-Collapse-Reg.

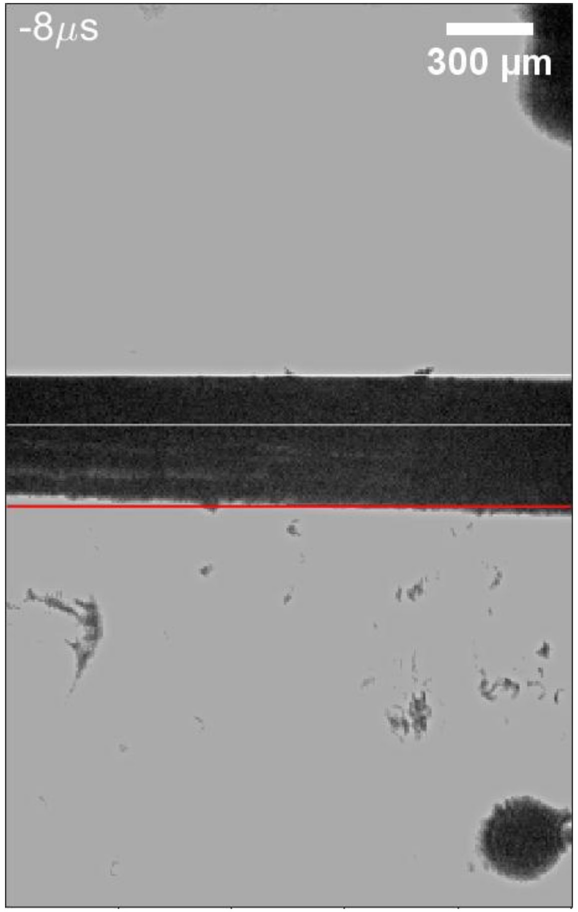


Move-through-Reg.

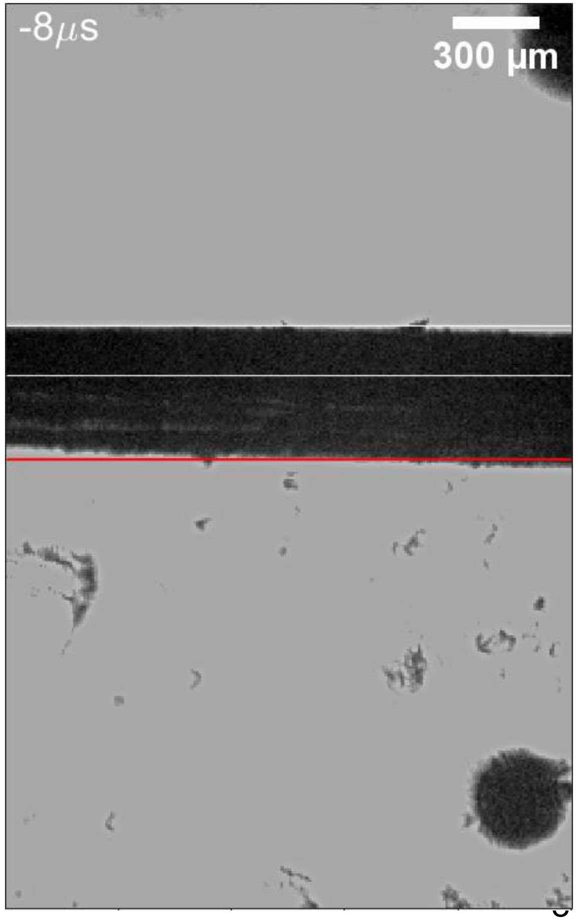


Reverse-Jet-Reg.

uniform

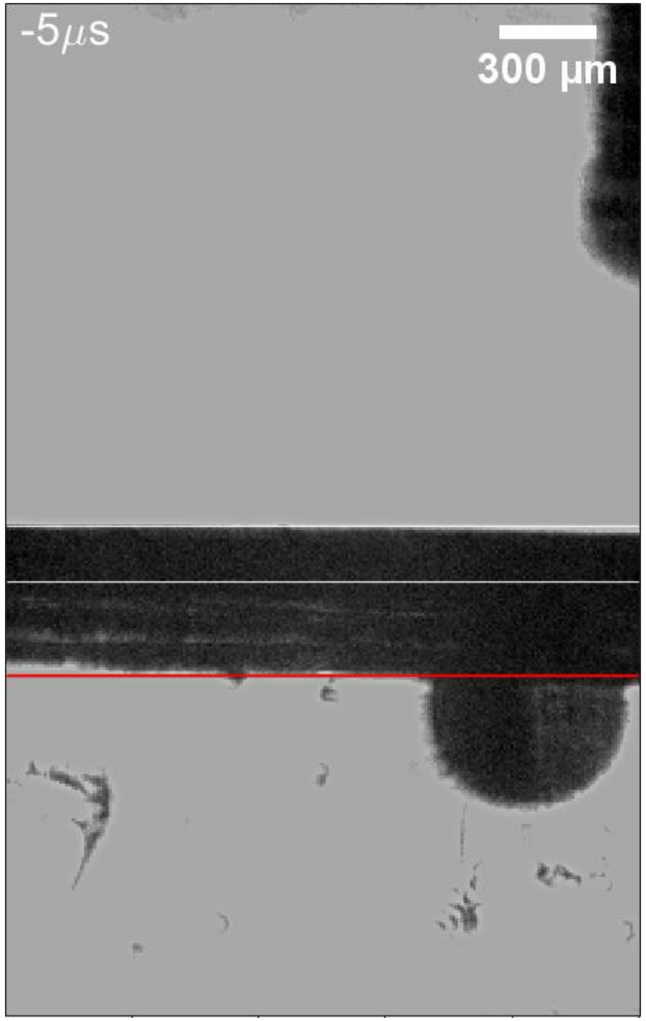


non-uniform

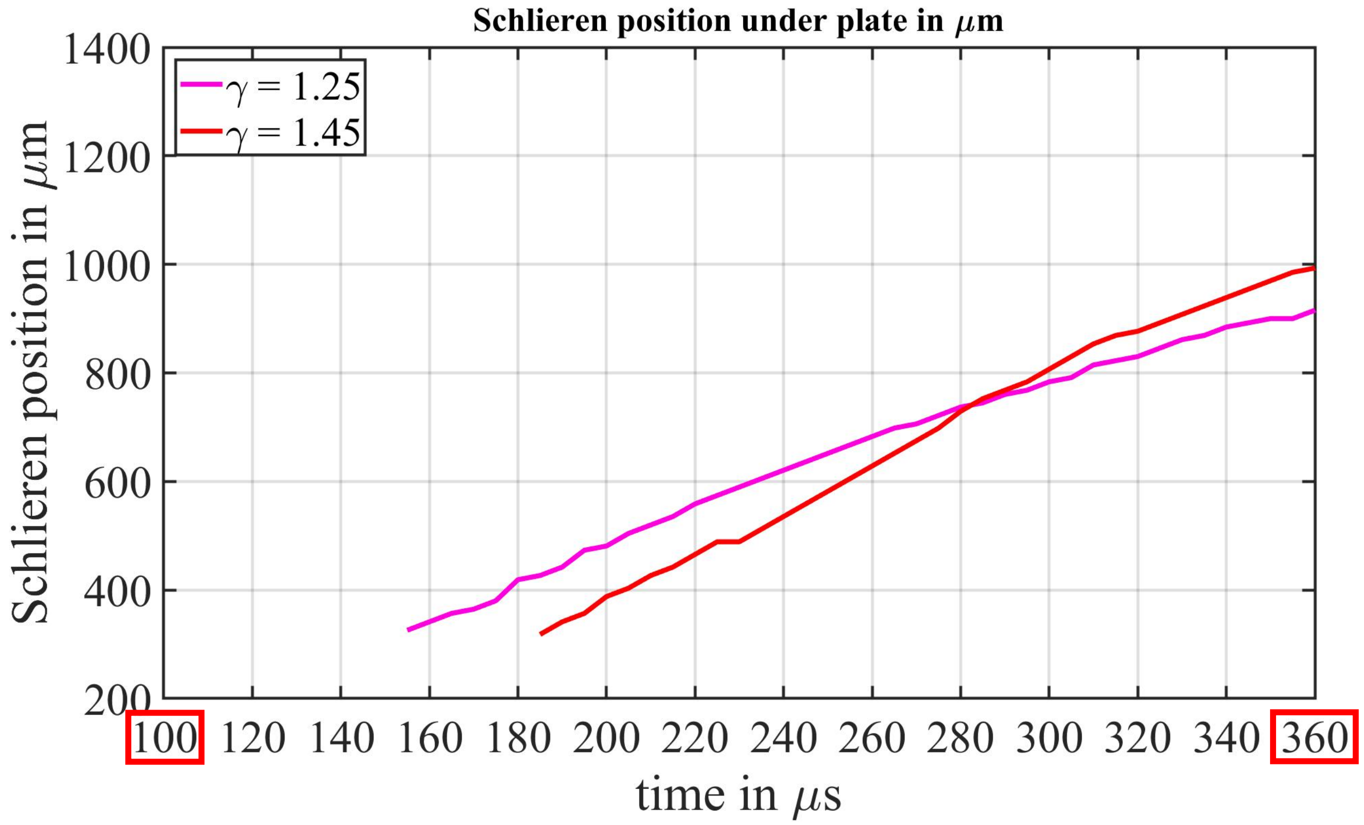


Second-Collapse-Region

γ = 1.25
@ 200kfps



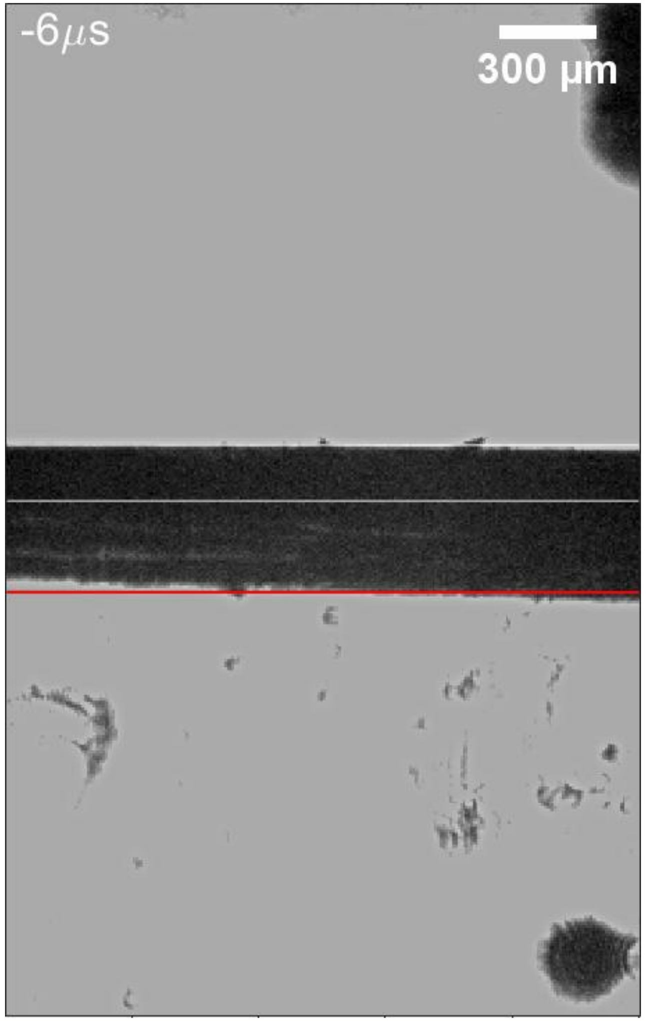
- Bubble expansion on one side
- Collapse also on same side
- Eff. only 2nd collapse induces pumping effect → energy loss

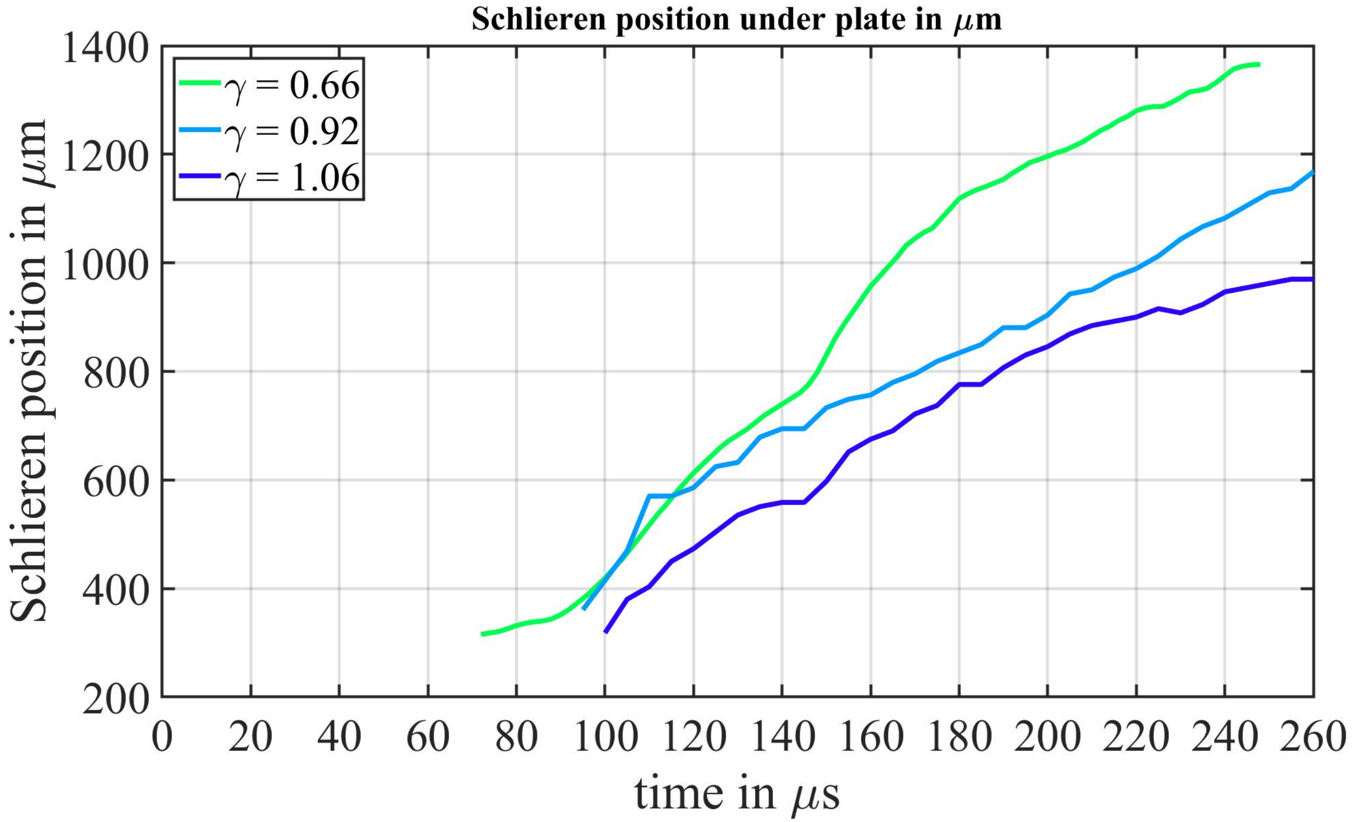


Move-through-Region

- Bubble expansion on one side
- Movement to other side
  → second collapse there

γ = 0.66
@ 500kfps

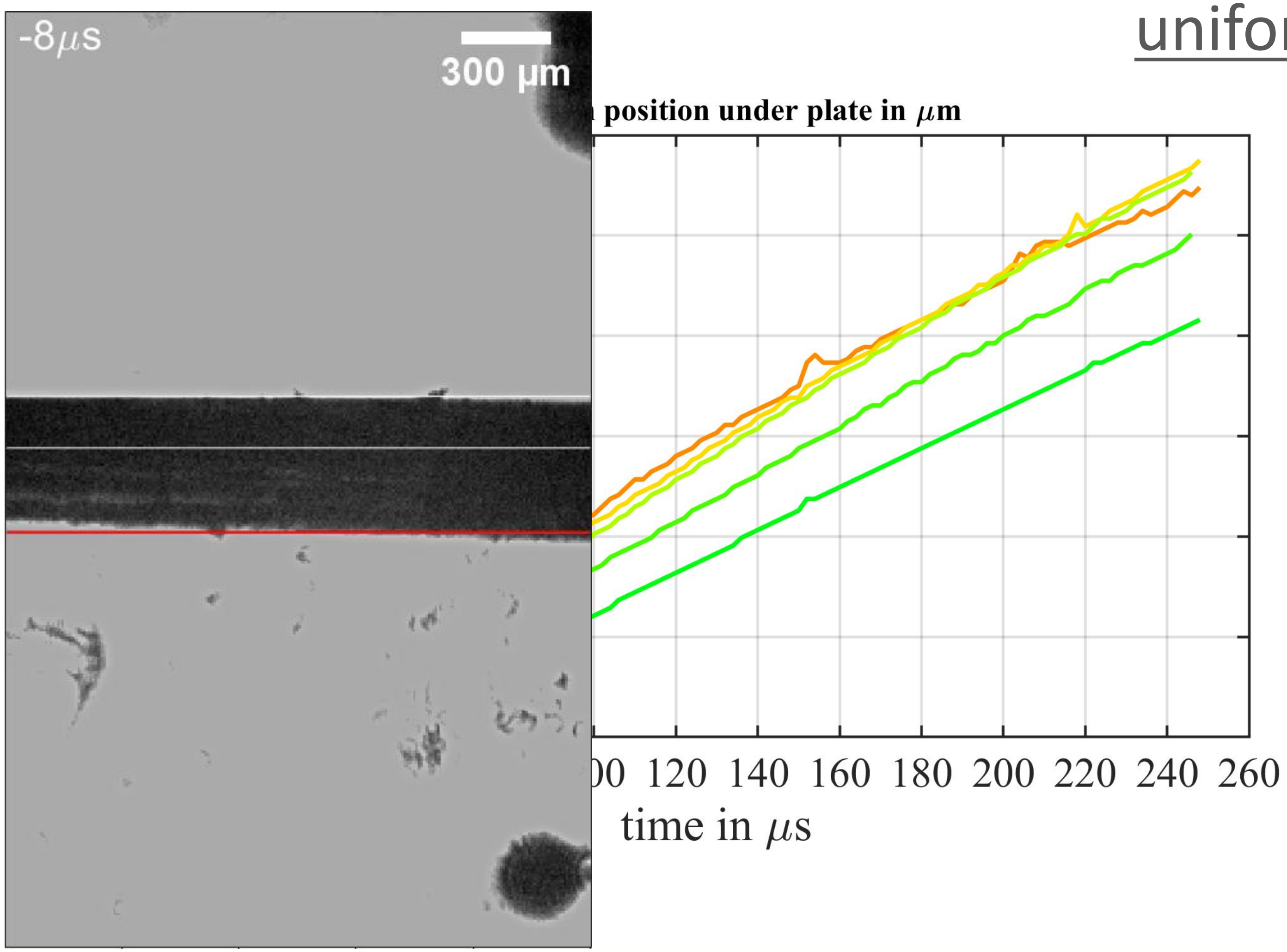




γ = 0.51
@ 500kfps

Reverse-Jet-Region

uniform



Sudden change in bubble behaviour

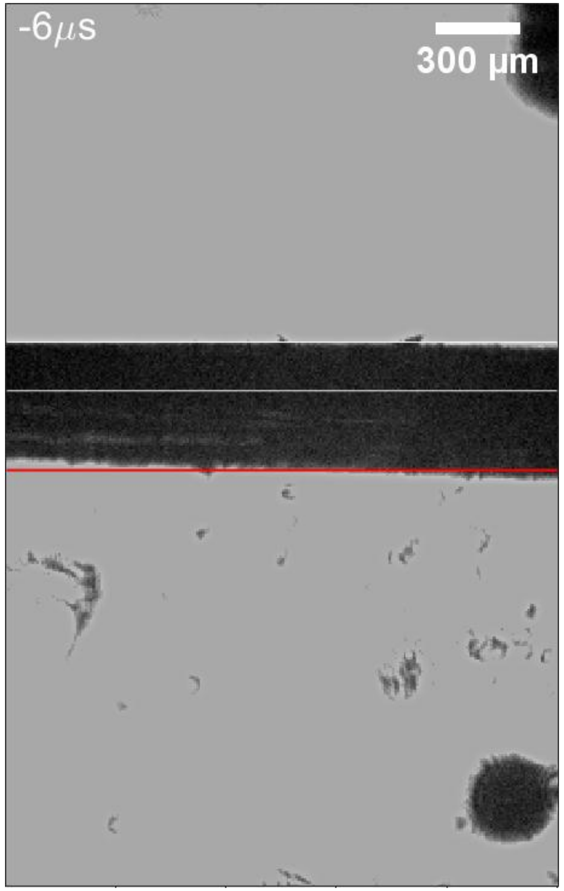
- Bubble expansion over plate
- Bubble stays there
- Linear schlieren position

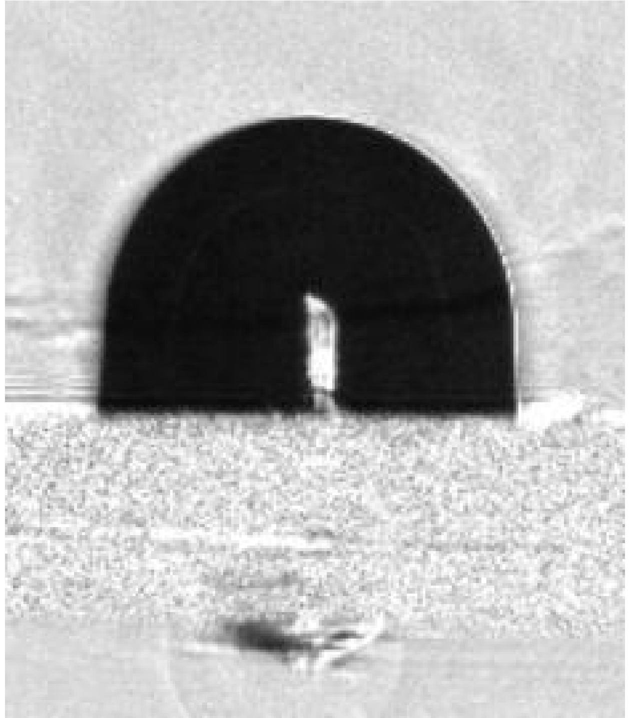
WHY??

- Bubble expansion on **both** sides
- collapse of smaller one
  → reverse jet

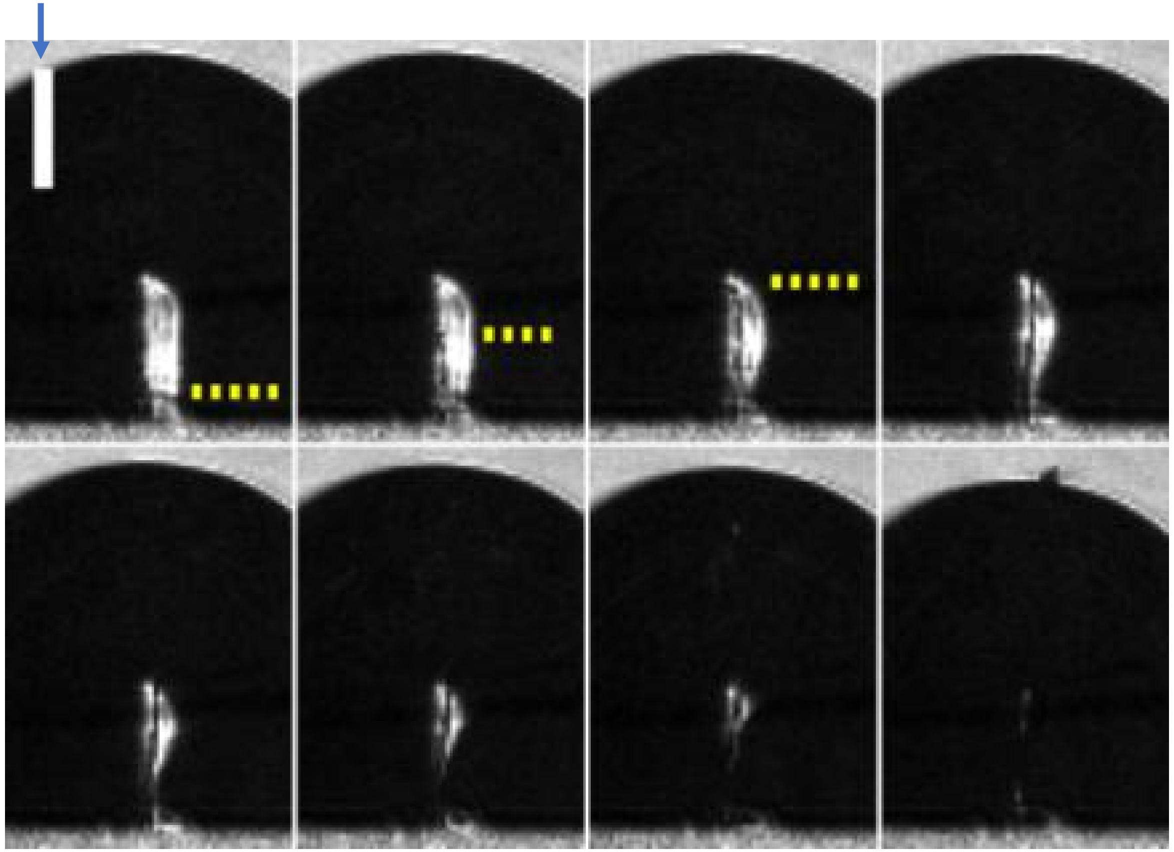
γ = 0.35
@ 500kfps

Reverse jet



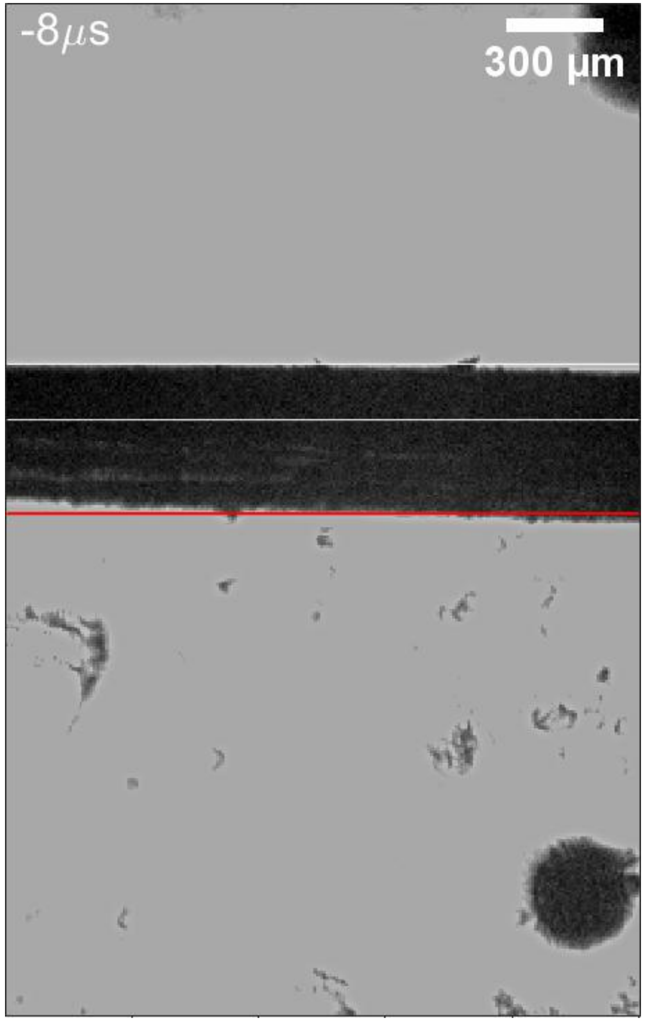


200 µm



Max. observed reverse jet velocity ≈ 41 .. 45 m/s

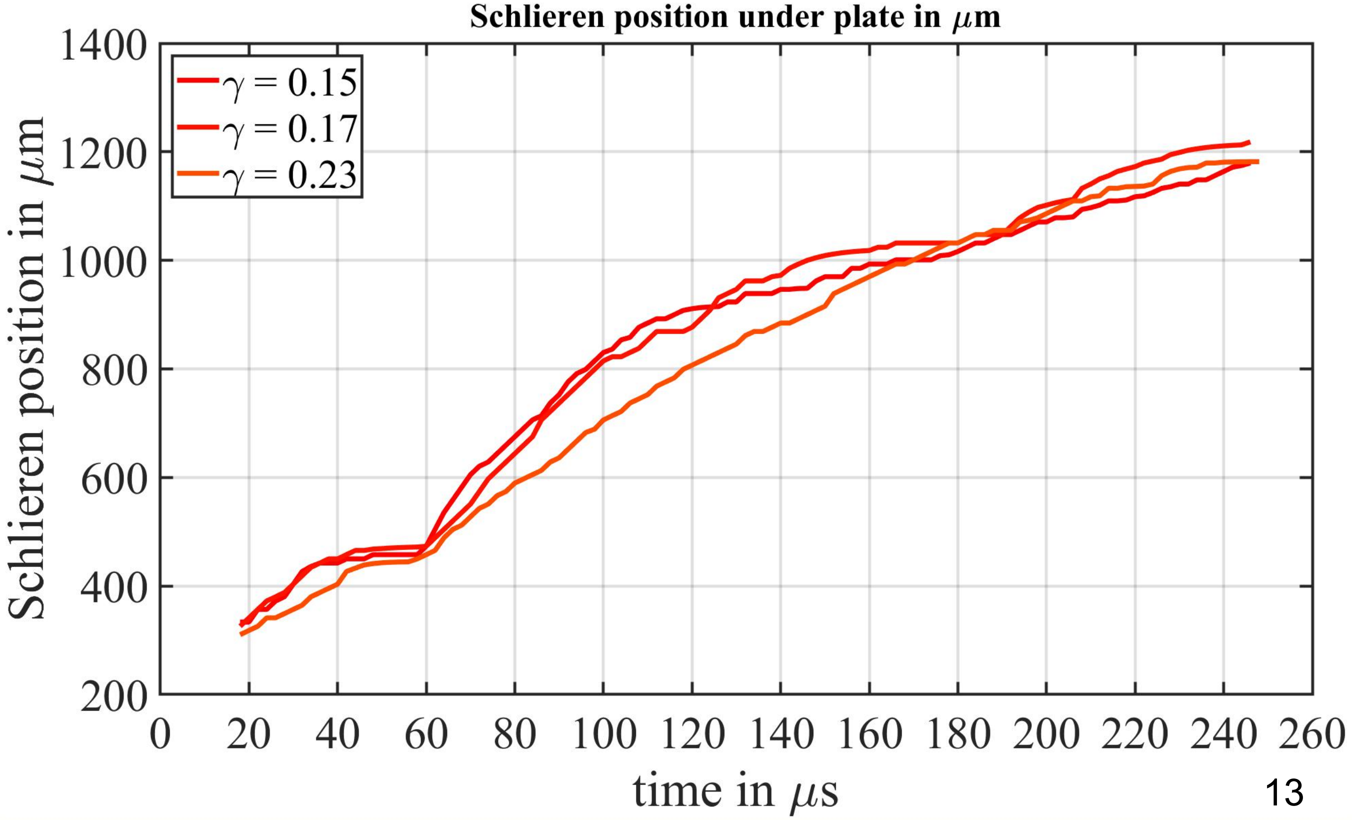
γ = 0.15
@ 500kfps



Reverse-Jet-Region

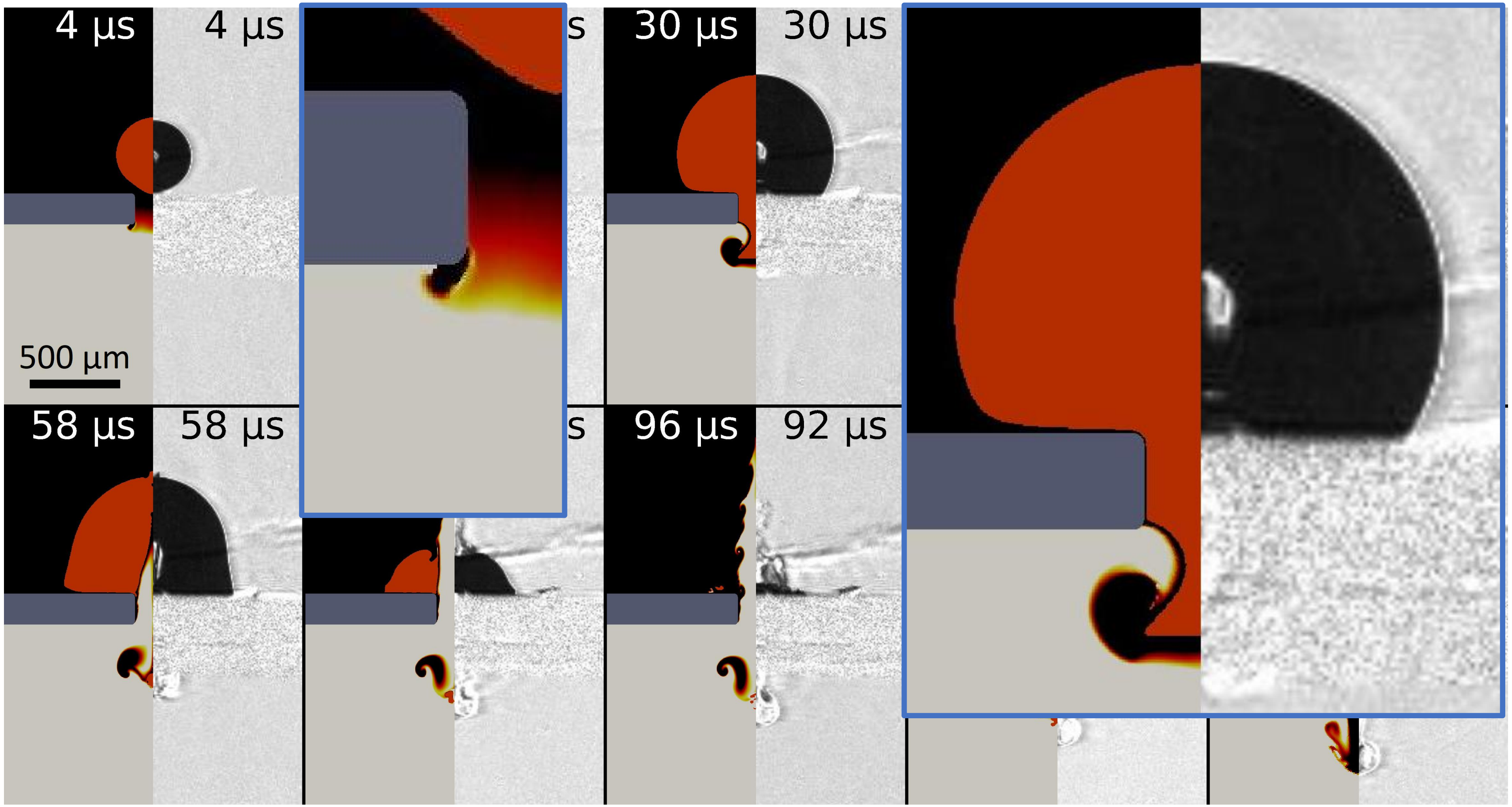
non-uniform

- Bubble expansion on both sides
- Early collapse of smaller one
  → reverse jet
- Bigger influence of lower bubble part
  → non-linear Schlieren



Comparison with simulation

Thanks to Hendrik Reese



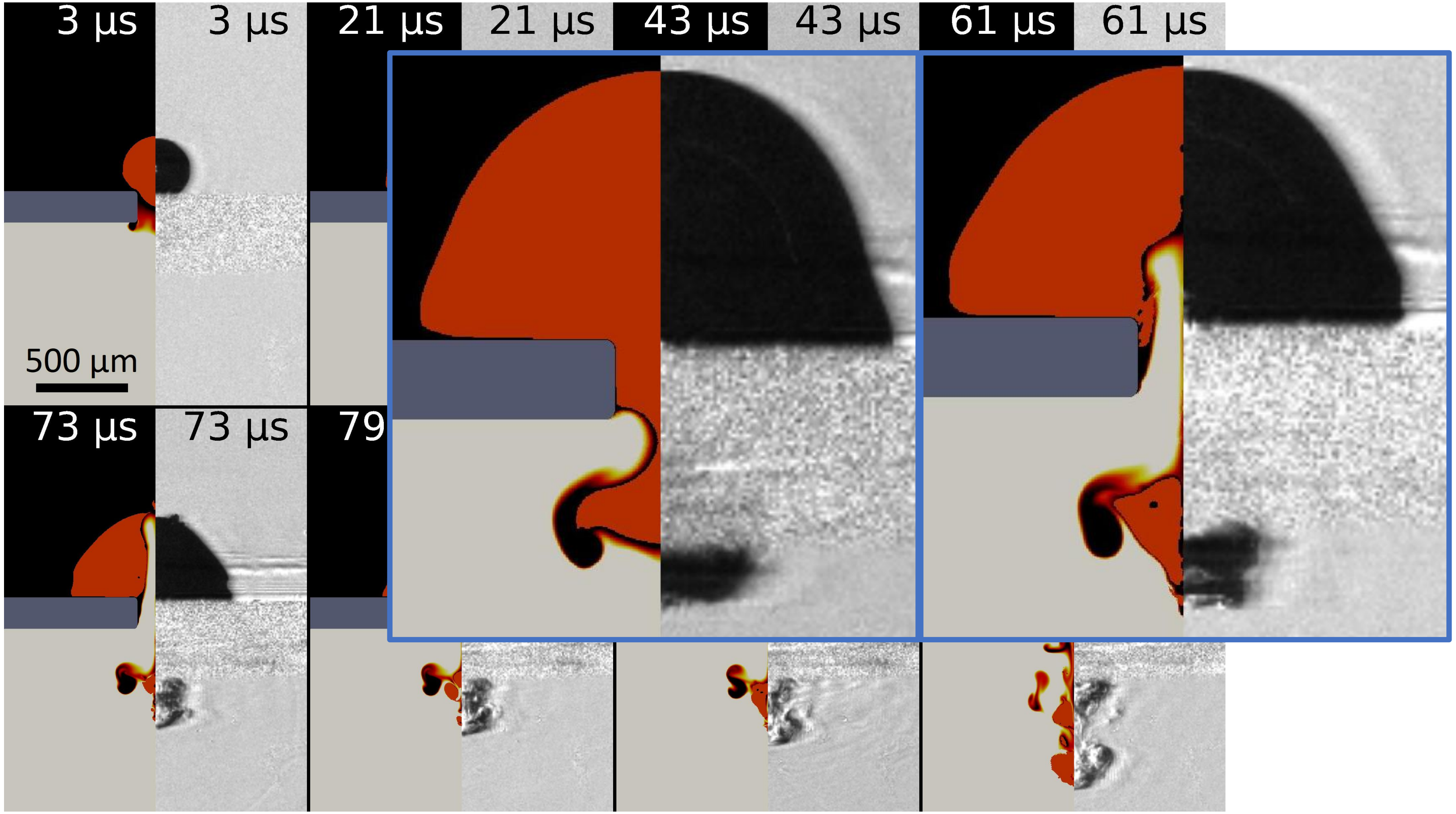
$\gamma = 0.44$

$d = 202$ µm

$R_{max} \approx 460$ µm

Thanks to Hendrik Reese

Comparison with simulation



$\gamma = 0.23$

$d = 108\ \mu m$

$R_{max} \approx 460\ \mu m$

Summary

- Schlieren technique employed to visualize the fluid movement from a single laser induced cavitation bubble
- Different regions depending on γ were identified and discussed in terms of their dynamics
- Reverse jet counteracts the pumping and changes bubble behaviour
- Similarity between experiment and simulation in overall behaviour, but discrepancies in timing

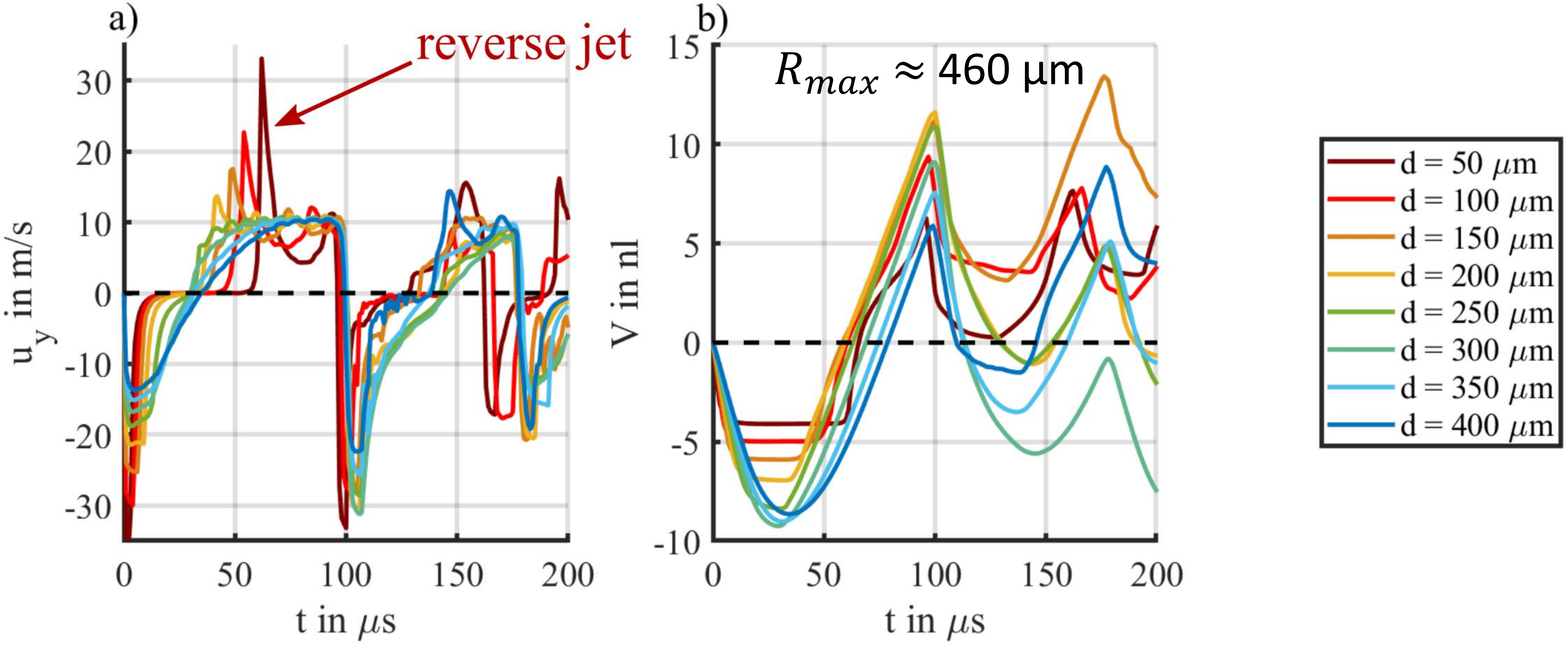
Outlook

- Change geometry (hole size, thickness)
- Further investigation on influence of flexibility
- Exploit reverse jet, e.g. Controlled Mixing

Thank you for your attention!

Literature

- Lew, K. S. F., Klaseboer, E., & Khoo, B. C. (2007). A collapsing bubble-induced micropump: An experimental study. *Sensors and Actuators, A: Physical.*
- Philipp, A., & Lauterborn, W. (1998). Cavitation erosion by single laser-produced bubbles. *Journal of Fluid Mechanics*, *361*, 75–116.
- Merzkirch, Wolfgang (2007): Density-Based Techniques. In: Tropea, Cameron/Yarin, Alexander L./Foss, John F. (Hg.): Springer Handbook of Experimental Fluid Mechanics. Springer-Verlag Berlin Heidelberg. S. 473–486.


a)
reverse jet
u_y in m/s
t in μs
b)
$R_{max} \approx 460$ µm
V in nl
t in μs
d = 50 μm
d = 100 μm
d = 150 μm
d = 200 μm
d = 250 μm
d = 300 μm
d = 350 μm
d = 400 μm