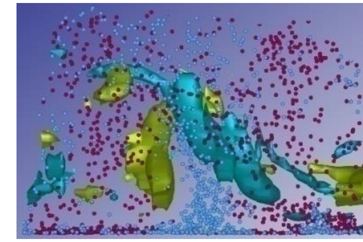
Università degli Studi di Udine

DIEGM: Dipartimento di Ingegneria Elettrica,

Gestionale e Meccanica



Cost effective drag reduction by bio-polymers in industrial size turbulent pipe flow

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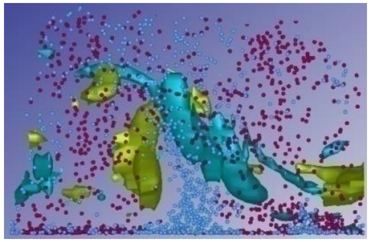
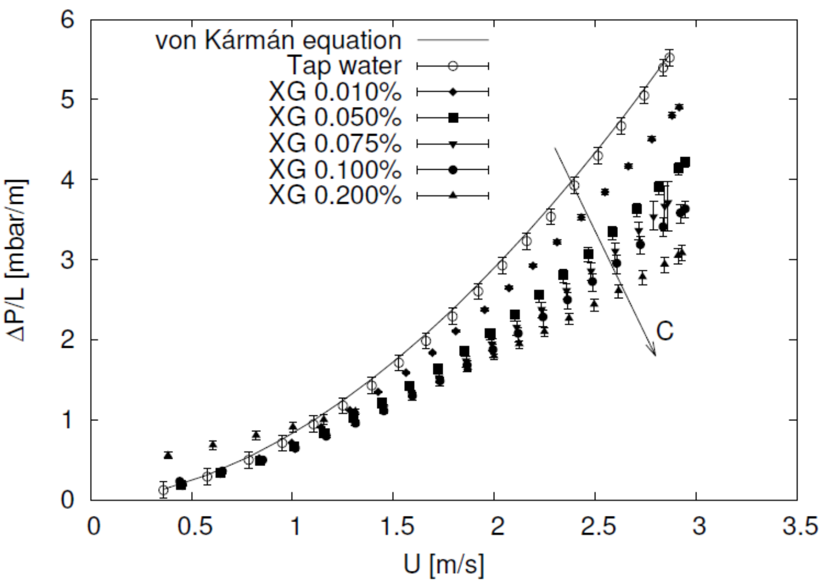
COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

7th Joint ERCOFTAC SIG43 Workshop and MC/WG Meeting
Stockholm, June 3rd-5th 2014



Motivation

It is known that bio-polymers can act as Drag Reducing Agents (DRA)

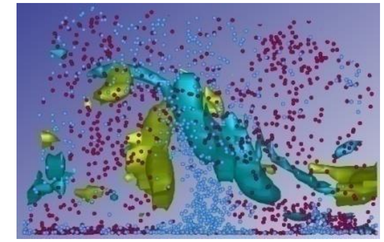


How much polymer should be added?

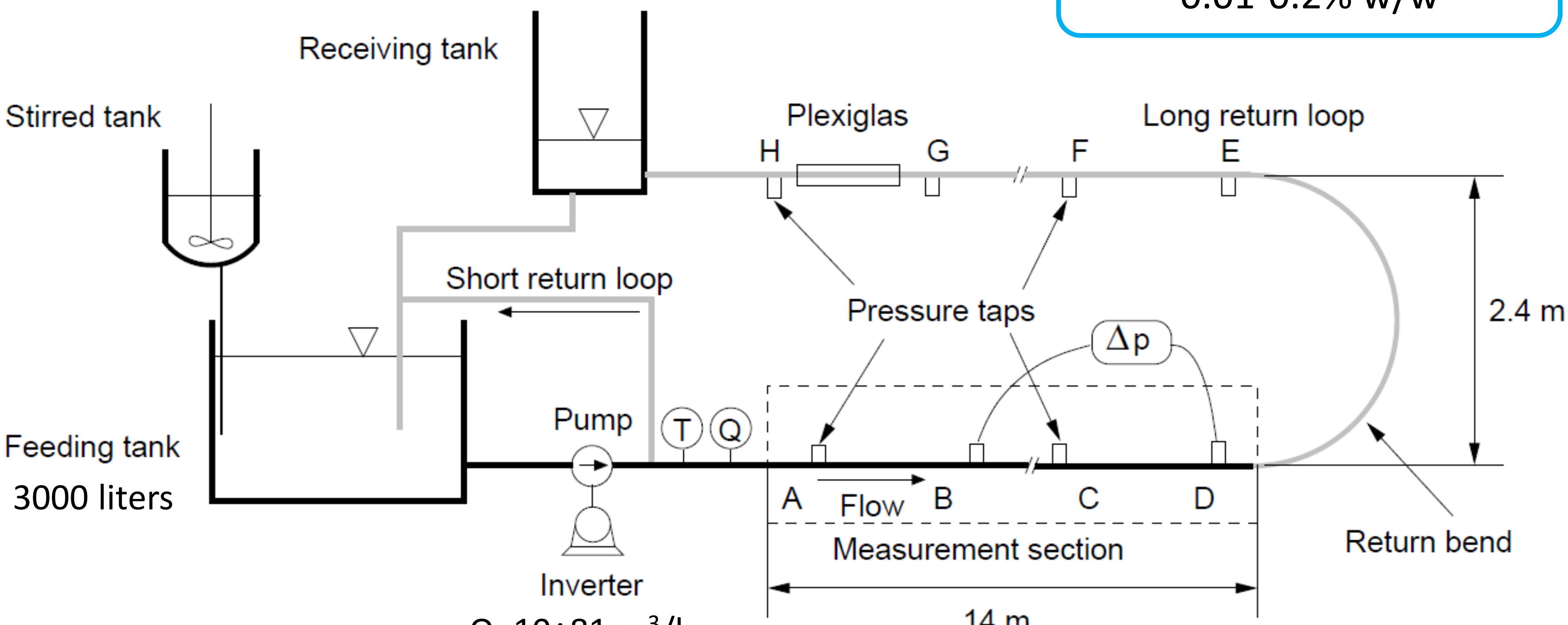
or

Can we evaluate the cost effectiveness?

Experimental rig



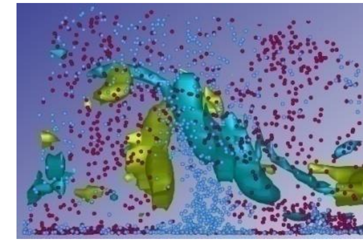
Xanthan gum
0.01-0.2% w/w

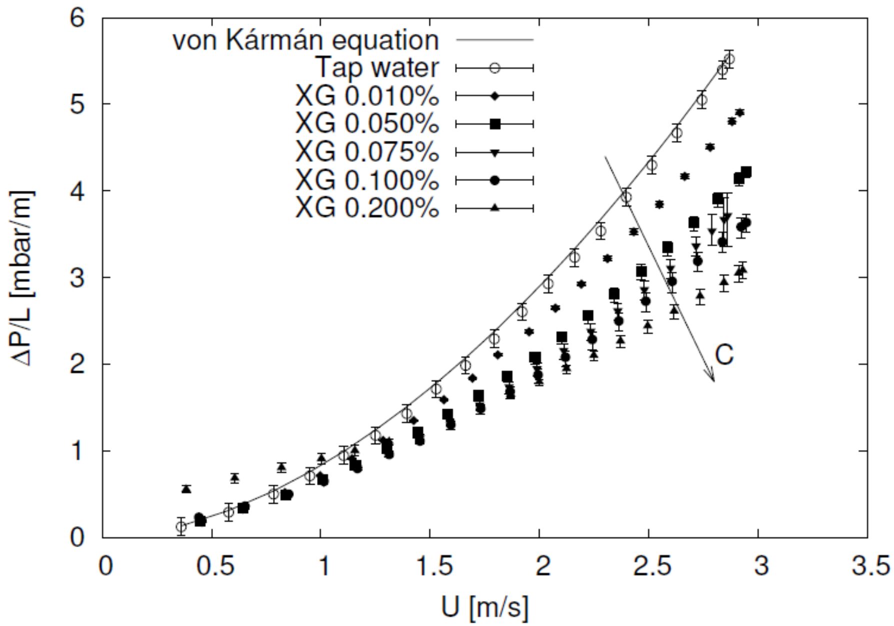


$Q \approx 10 \div 81\ m^3/h$
(3÷23 l/s)

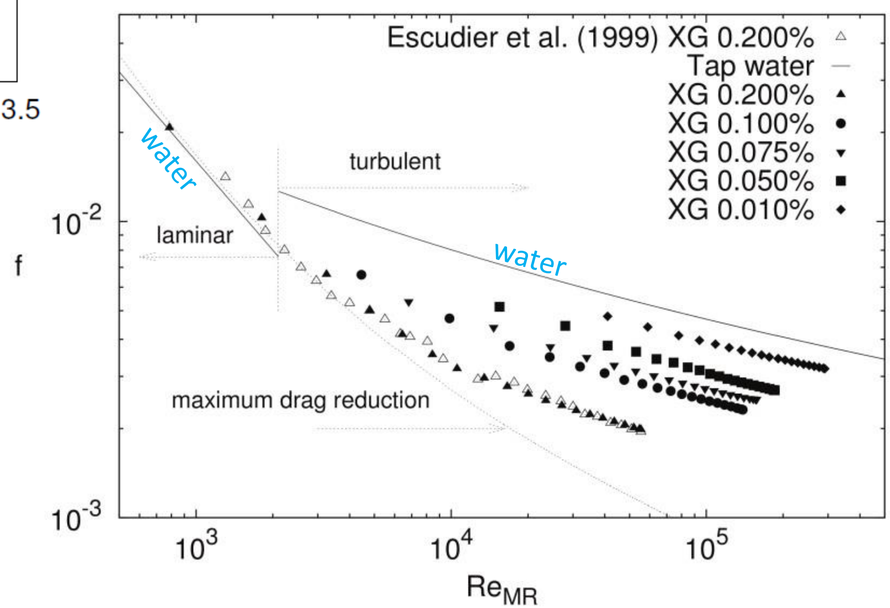
Re≈4.8e4 ÷ 3.6e5
(pure solvent)

Drag reduction results



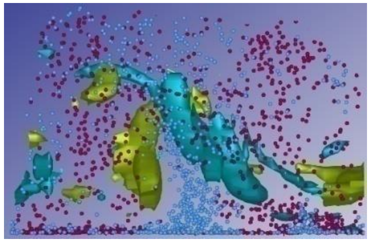


As %C ↑ ⟹ Δp ↓



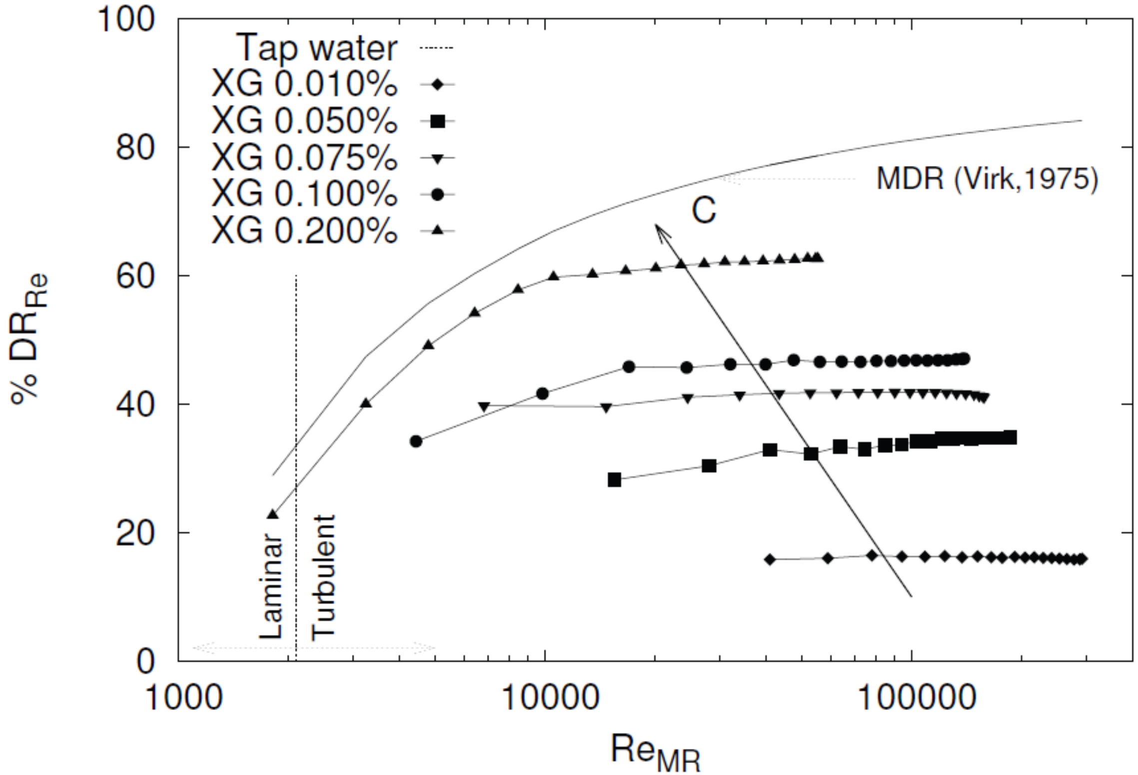
$$Re_{MR} = \frac{\rho U D}{\eta^*}$$

$$\eta^* = \eta\left(\frac{3n_{pl}+1}{4n_{pl}}\right)$$

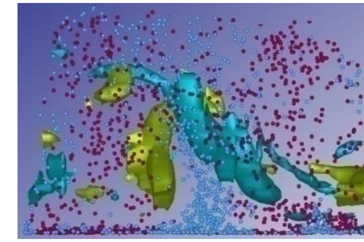


Drag reduction results: %DR

$$\%DR_{Re} = 100 \cdot \left. \frac{f_w - f_p}{f_w} \right|_{Re=const}$$

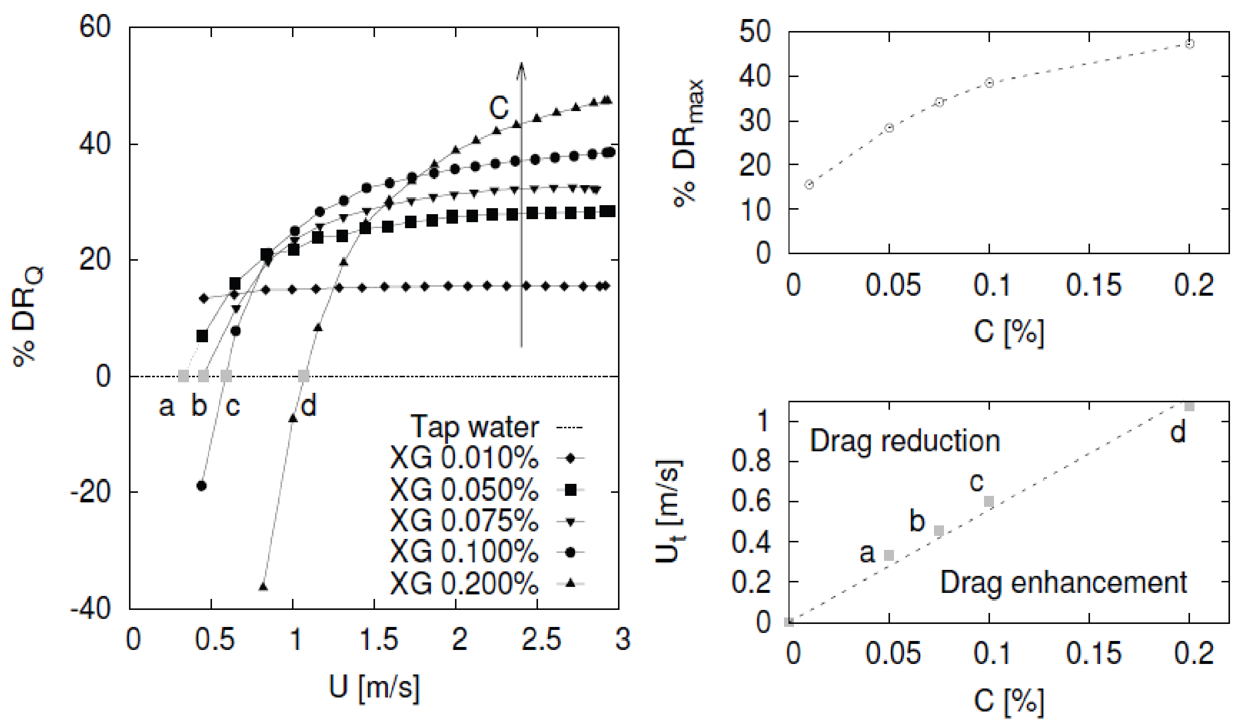


Drag reduction results: %DR

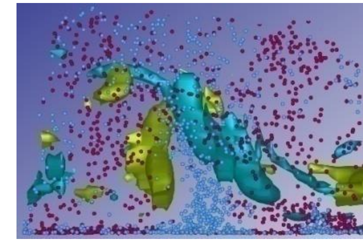


$$\%DR_Q = 100 \cdot \frac{\Delta p_w - \Delta p_p}{\Delta p_w}\bigg|_{Q=const}$$

Industrial approach: energy saving

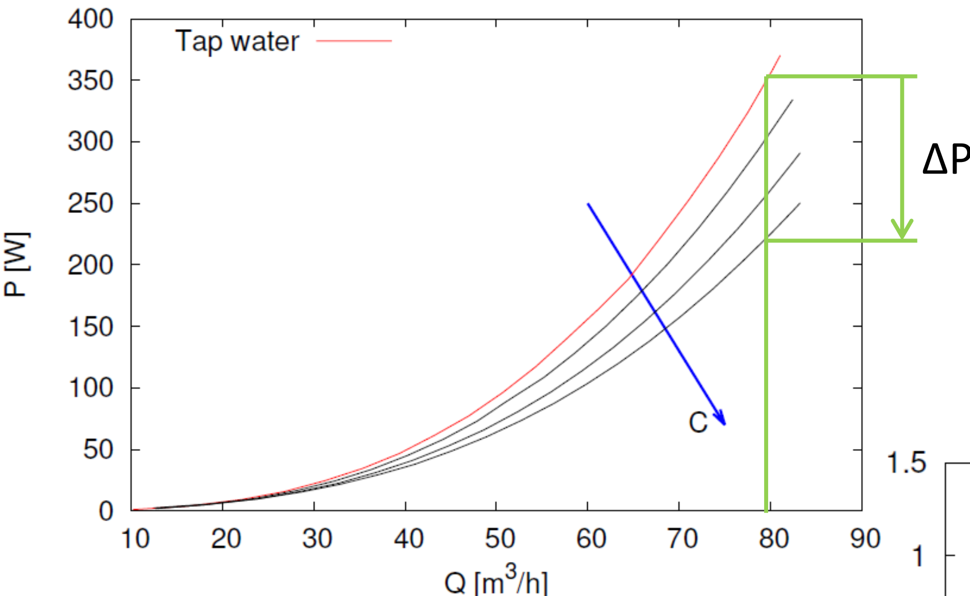


Cost-effective analysis 1/4



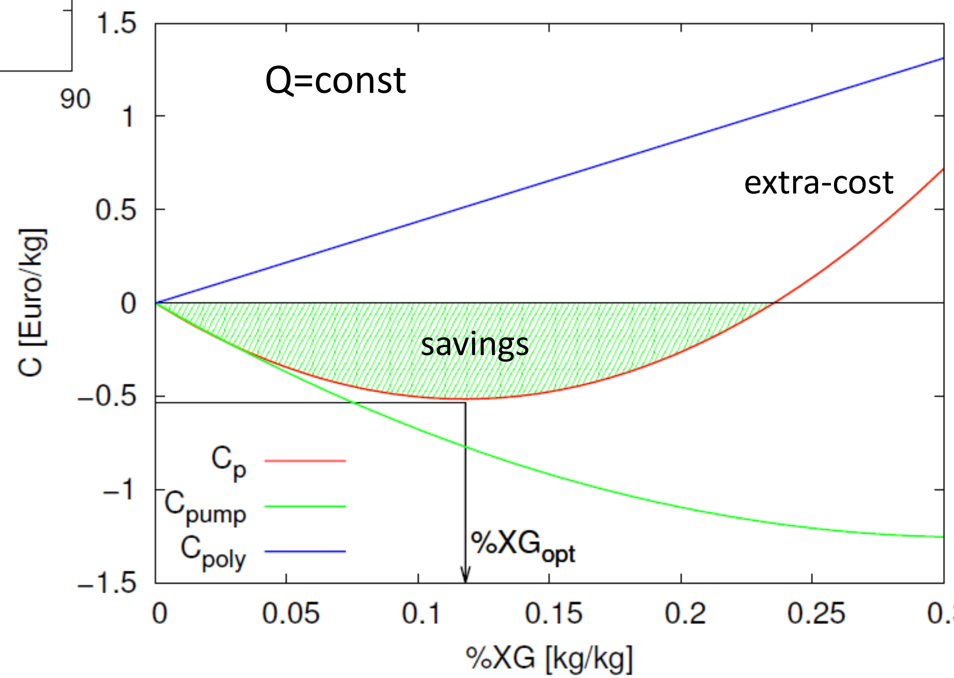
Hypothesis

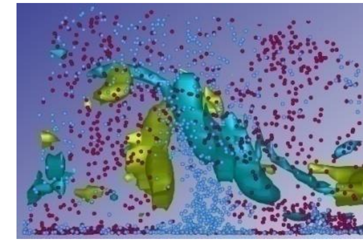
Once through pipeline



$$P = \Delta p \cdot Q$$

$$P \propto Q^3$$





Cost-effective analysis 2/4

Percentage of saving

$$\%S = \frac{C_p - C_w}{C_w} \quad [\%]$$

Transport cost per unit mass

$$C_w = \frac{K_E \Delta p_w Q N_h}{\rho Q N_h} \quad [€/\text{kg}]$$

without DRA

$$C_p = \frac{K_E \Delta p_p Q N_h}{\rho Q N_h} + \%XG \cdot K_p \quad [€/\text{kg}]$$

with DRA

K_E [€/kW] cost of energy per unit power

Δp [Pa] pressure loss

Q [m^3/h] flowrate

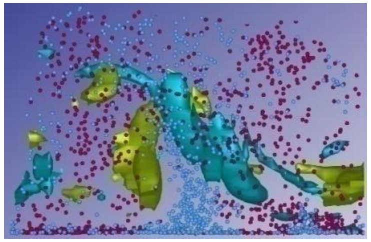
N_h [h] number of pump working hour

ρ [kg/m^3] fluid density

$\%XG$ [kg/kg] concentration of DRA

K_p [€/kg] cost of DRA per unit mass

Cost-effective analysis 3/4



$$\Delta p_p = \left(1 - \%DR_Q\right)\Delta p_w \qquad \Delta p_w = 2\rho f_w U^2 \frac{L}{D}$$

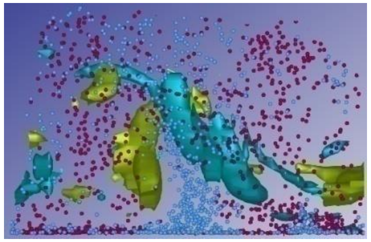
$$\%S = -\%DR_Q + \frac{1}{\alpha}\frac{\%XG}{2 f_w U^2}$$

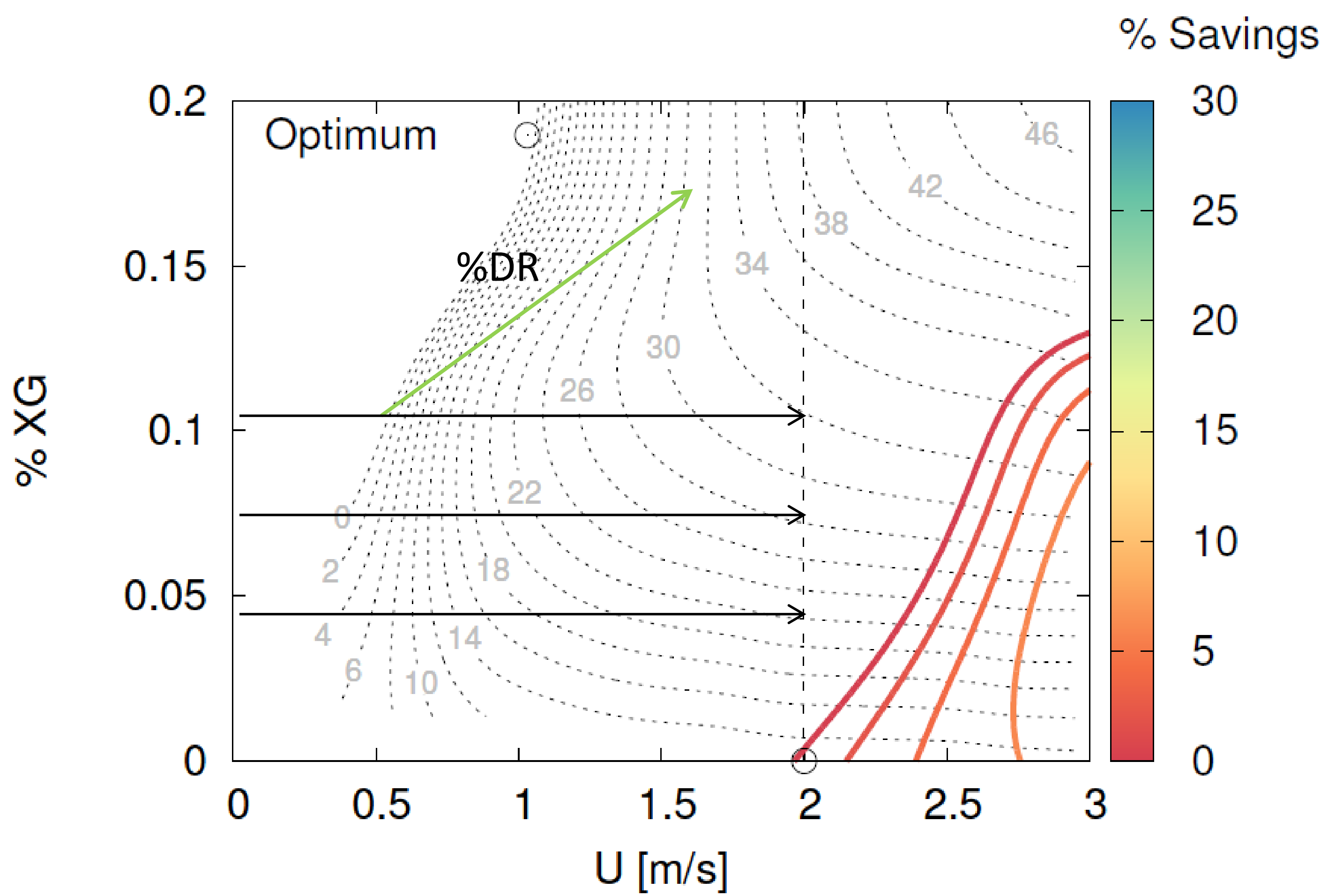
$$\alpha = \frac{K_E}{K_p}\frac{L}{D}$$

$$\%S = f\left(U, \%XG, \alpha\right)$$

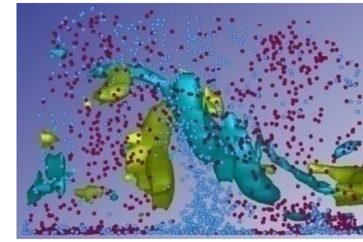
DRA cost-effective ONLY IF %S>0

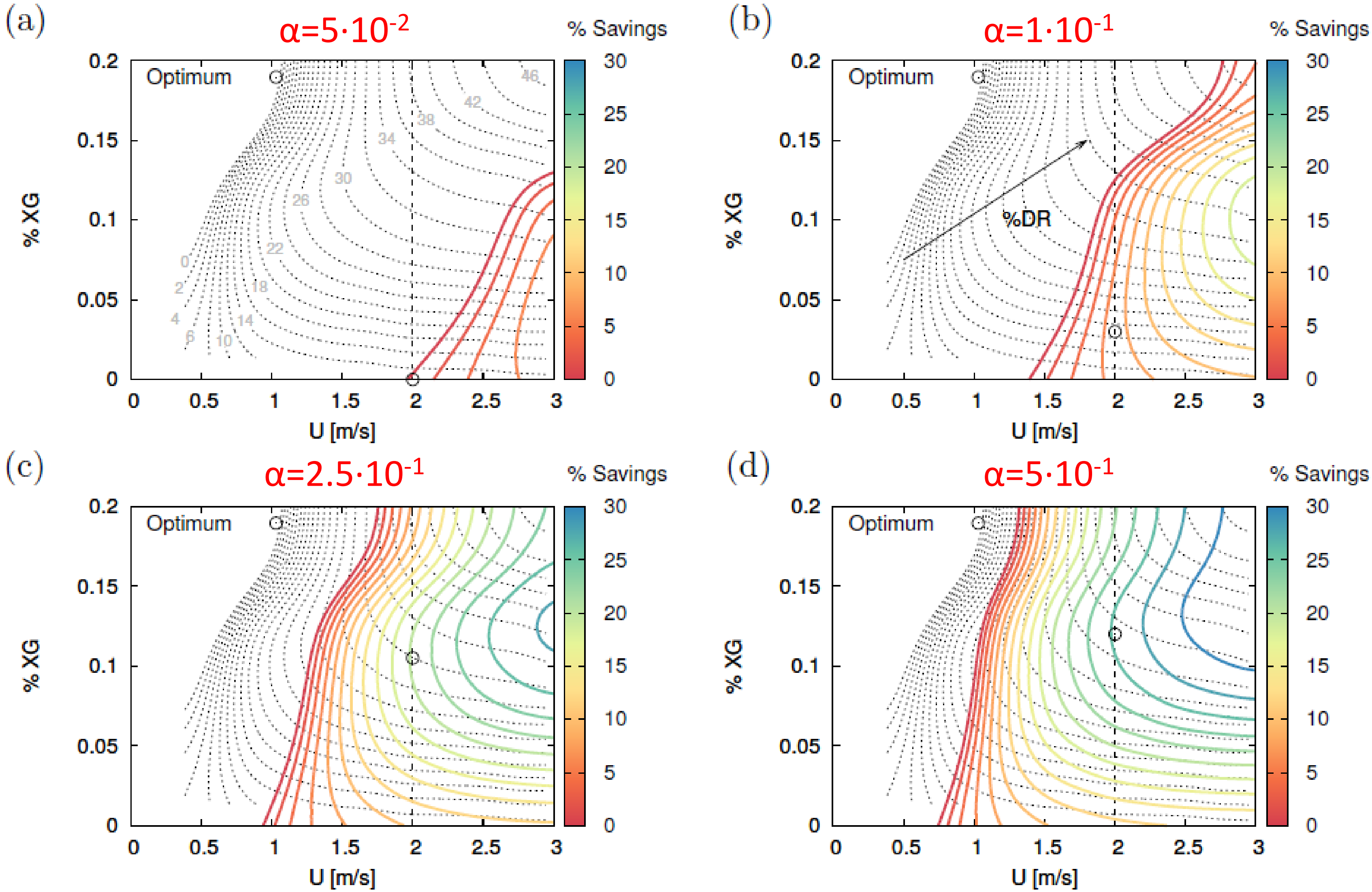
Cost effective analysis 4/4

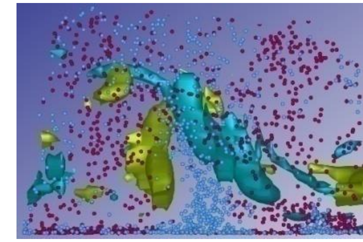




Cost effective analysis 4/4

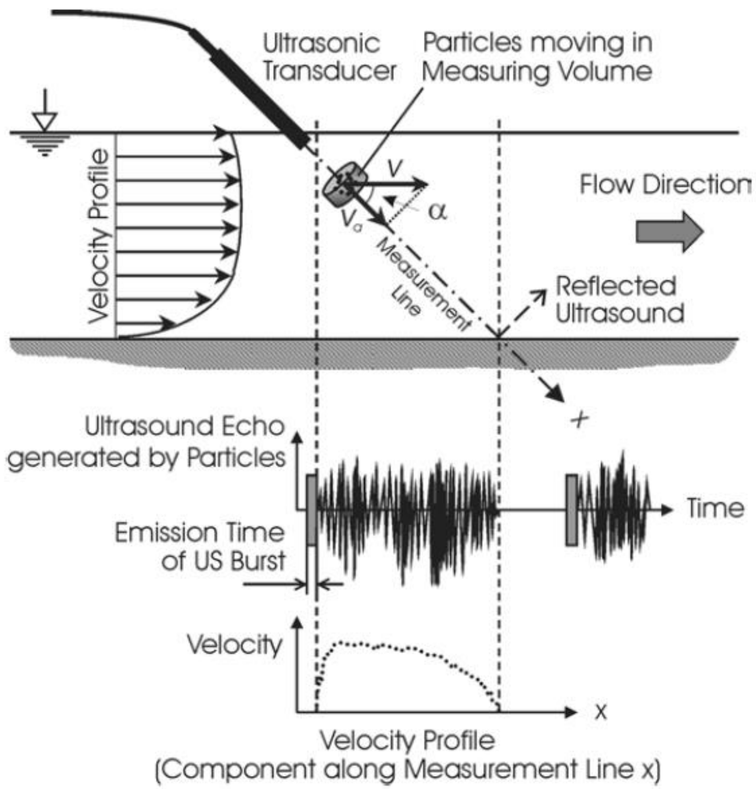






What's next?

Ultrasonic Velocity Profile (UVP) measurements



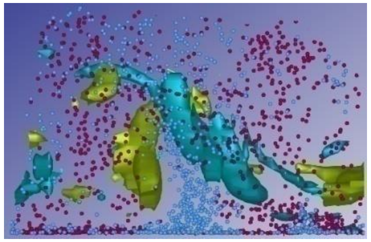
$$f_d = f_0 - f' = f_0 \frac{2v_a}{c}$$

$$v_a = \frac{c f_d}{2 f_0}$$

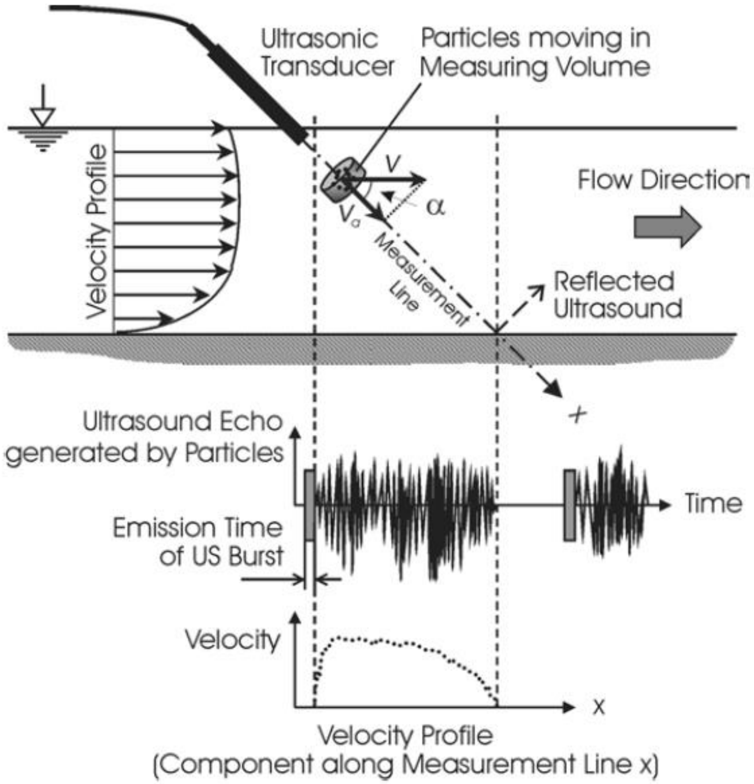
$$v = \frac{v_a}{\cos\alpha} = \frac{c f_d}{2 f_0 \cos\alpha}$$

- v [m/s] velocity of particle
- v_a [m/s] velocity of particle along probe axis
- α [°] Doppler angle
- f_d [Hz] Doppler shift frequency
- c [m/s] speed of sound in propagating medium
- f_0 [Hz] frequency emitted by the transducer

What’s next?



Ultrasonic Velocity Profile (UVP) measurements



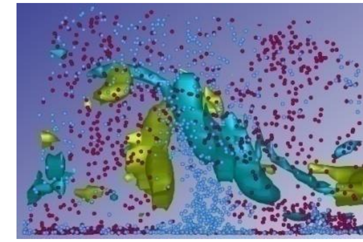
$$y_a = \frac{c\Delta t}{2}$$

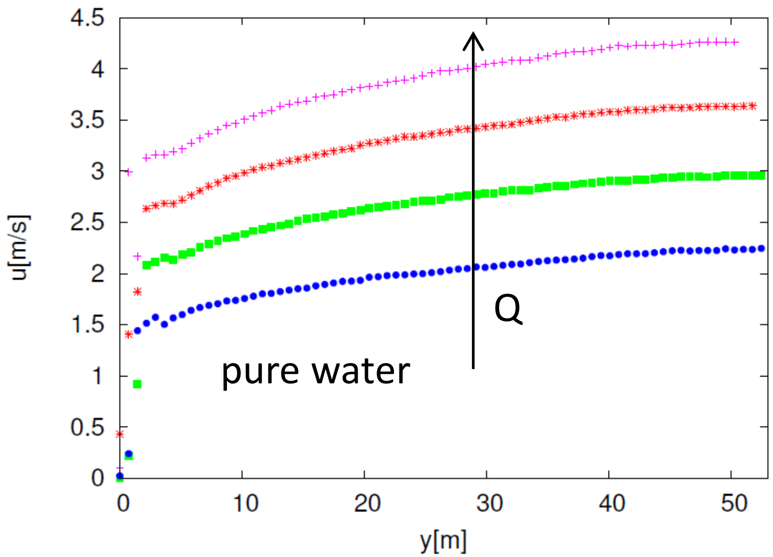
$$y = y_a \sin\alpha$$

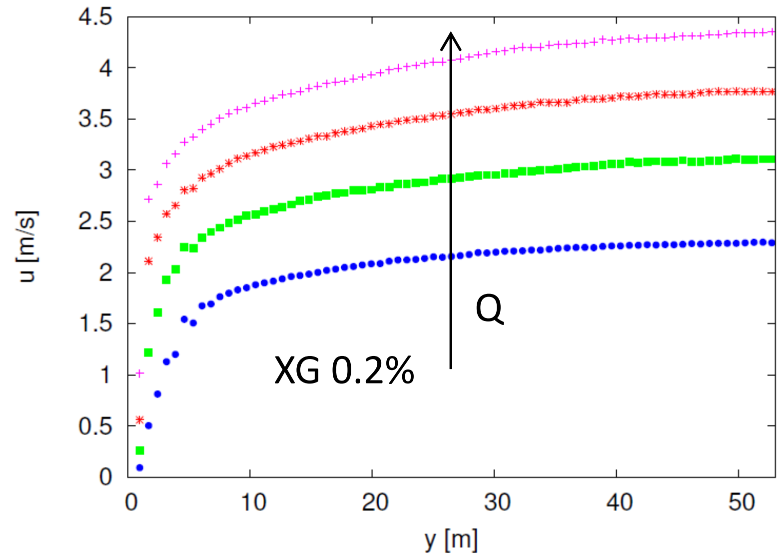
y [m] distance of the particle from the transducer

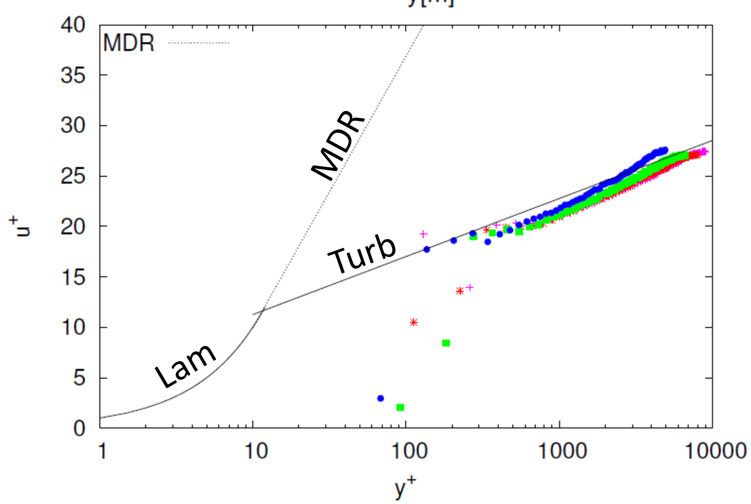
Δt [s] time delay between pulse emission and reception

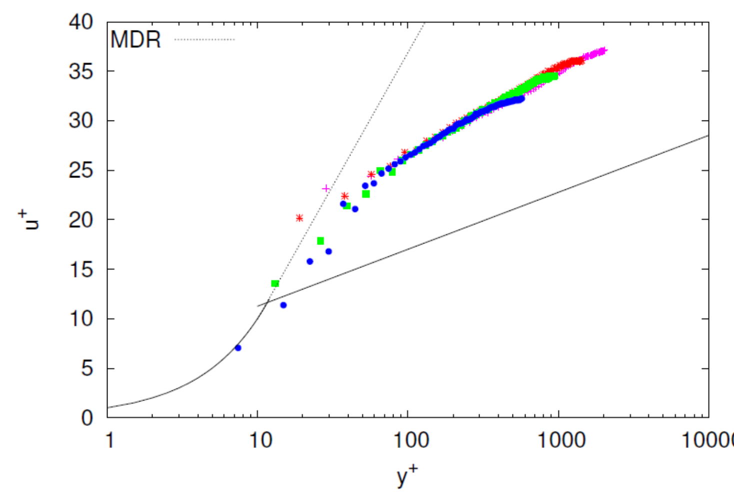
What’s next?



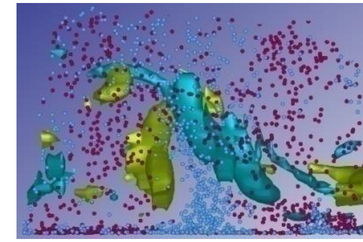

4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
u[m/s]
y[m]
Q
pure water

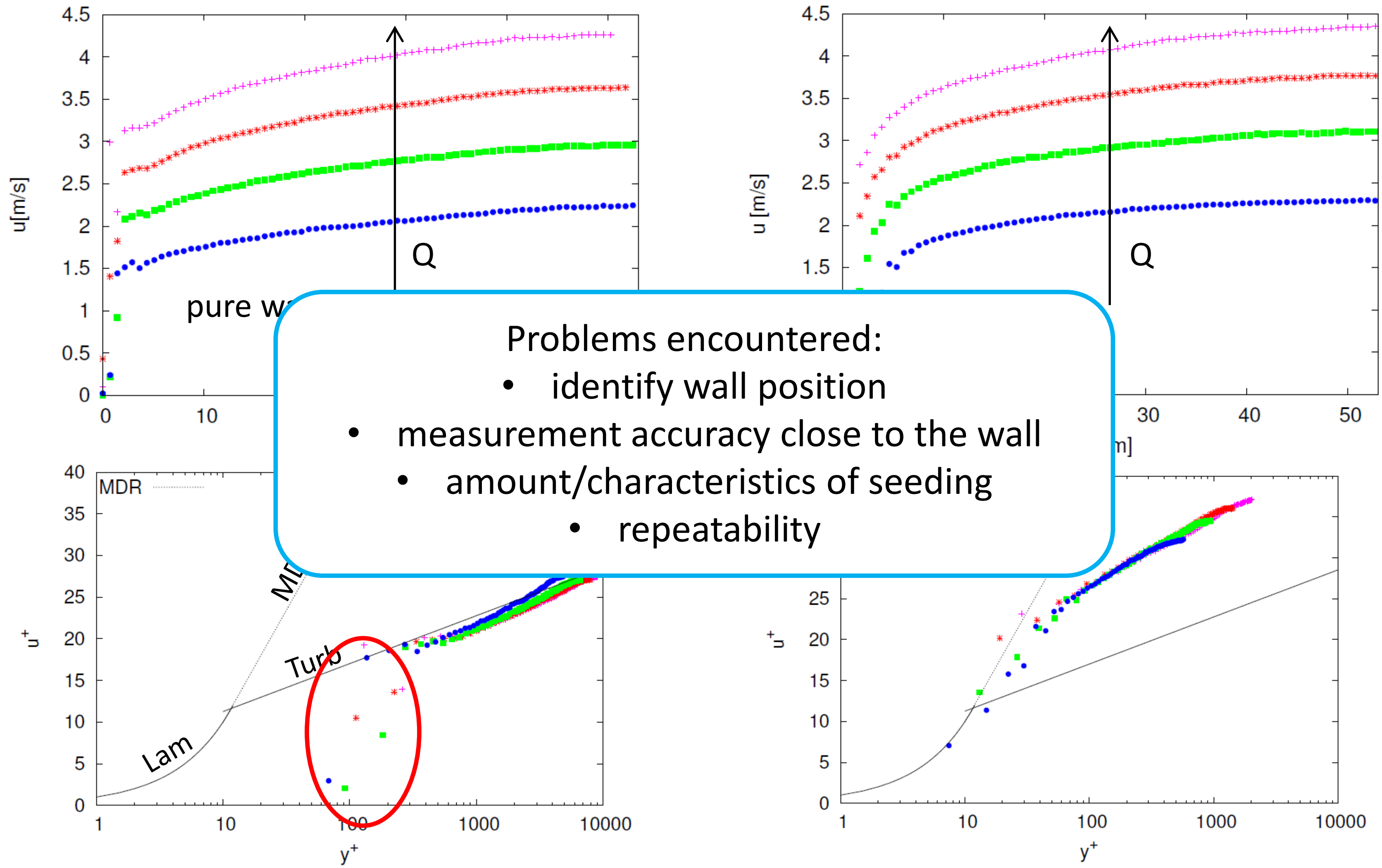

4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
u [m/s]
y [m]
Q
XG 0.2%


40
35
30
25
20
15
10
5
0
1
10
100
1000
10000
MDR
MDR
Turb
Lam
u+
y+


40
35
30
25
20
15
10
5
0
1
10
100
1000
10000
MDR
u+
y+

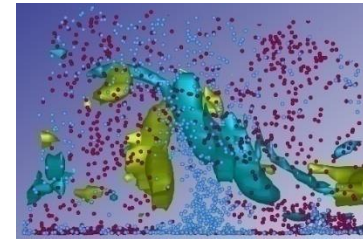
What's next?





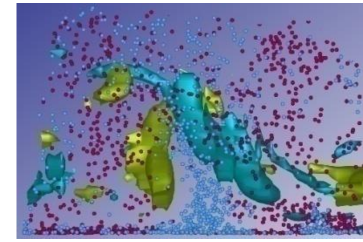
Problems encountered:

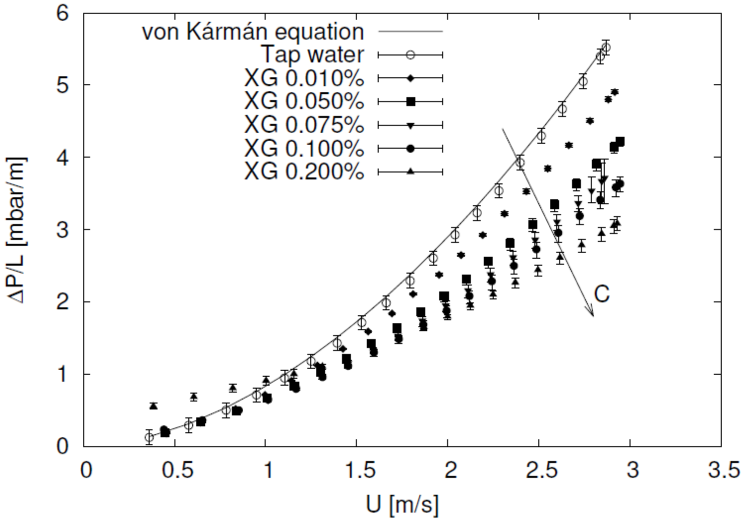
- identify wall position
- measurement accuracy close to the wall
- amount/characteristics of seeding
- repeatability



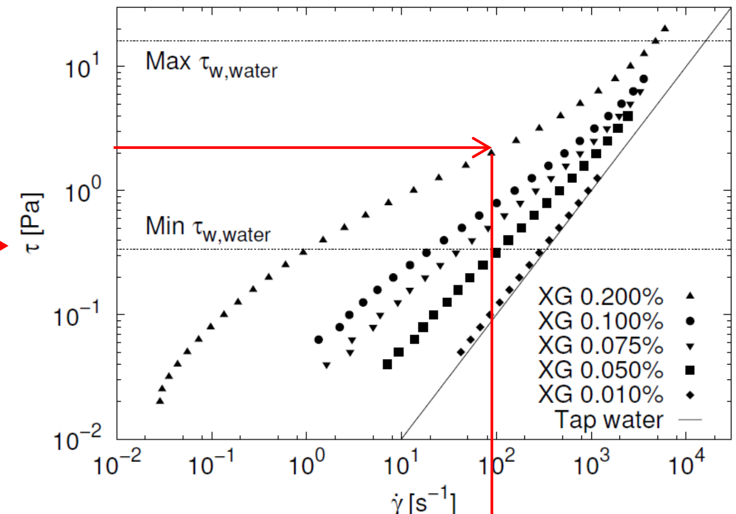
Thanks for your attention

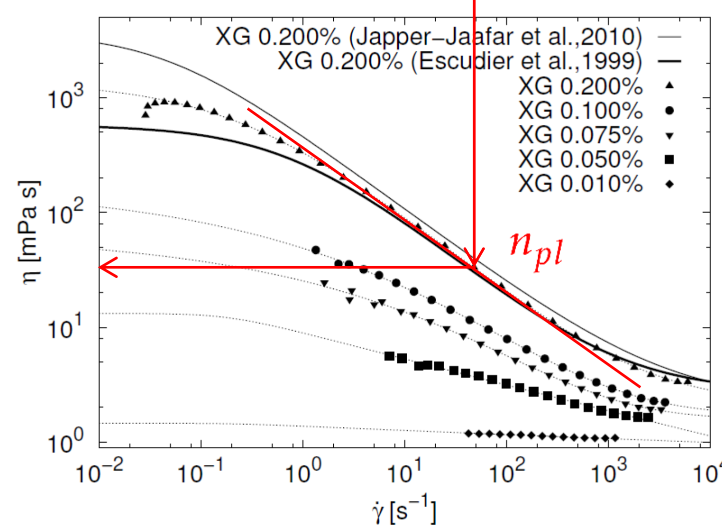
Viscosity & Reynolds number





$$\tau_w = \frac{\Delta p D}{4L}$$





$$\eta$$
$$n_{pl}$$

$$Re_{MR} = \frac{\rho U D}{\eta^*}$$

$$\eta^* = \eta\left(\frac{3n_{pl}+1}{4n_{pl}}\right)$$