Micro-channel studies with CO_2 at University of Twente

first measurements and future plans

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Introduction

μ-channel cooling →

- Cooling high power density particle physics pixel detectors
- Minimize material budget
- High heat transfer coefficient (HTC)

Gap on simulation and prediction models →

- Preliminary simulation model developed until now for CO_2 is suited for horizontal evaporators with equivalent diameter down to 1.4 mm
- For μ-channels (<1 mm) ; no specific prediction model exists for pressure drop and HTC for CO_2
- Prediction model exists for other refrigerants (R236-fa, R245-fa, R134-a tested at above 0^oC)

Studies summary

Studies focus on →

- Extending simulation model to μ-channels
- Validation of existing prediction models with quantitative CO_2 flow measurements at -30°C to 20°C (Pressure drop, HTC, Flow regime) for various ID

Mainly focus on →

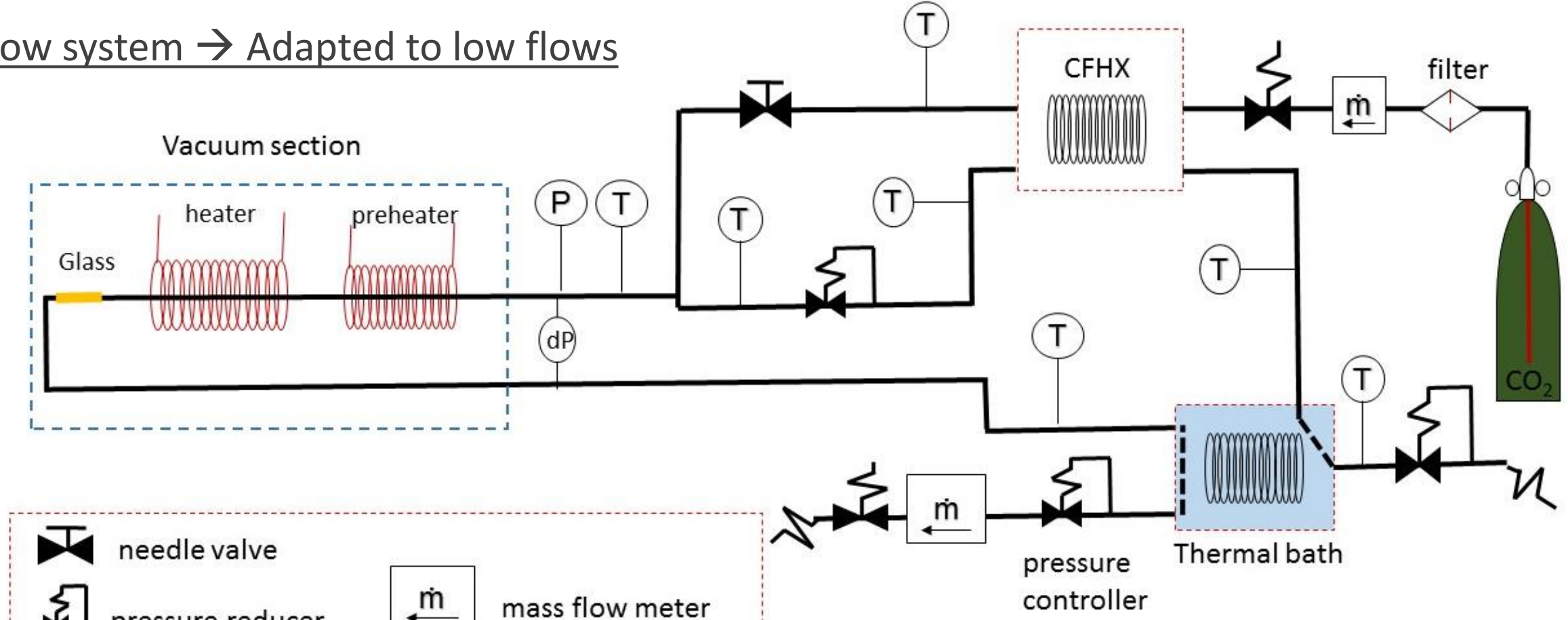
❑ Single straight circular μ-channel mainly stainless steel ID 0.25 mm followed by a glass section (fused silica with coating, thickness ~ 0.10 mm)

➢ Measurement matrix at -20 °C evaporation temperature (Mass flow, Power)

❑ Silicon-pyrex device with multiple straight rectangular μ-channels (~ID 0.20 mm)

➢ Measurement matrix (Power, Evaporation temperature)

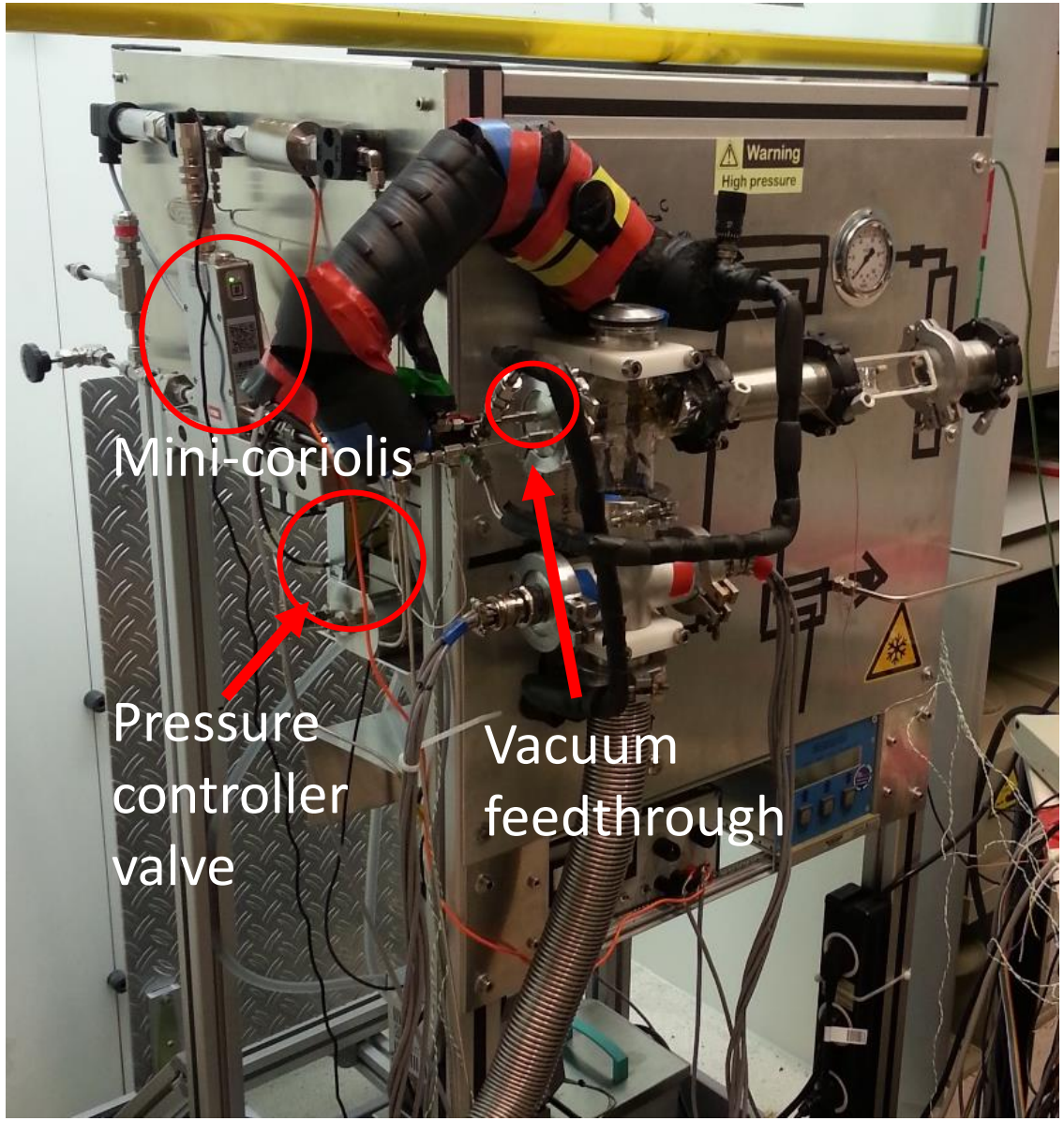
Blow system → Adapted to low flows



2 pressure levels to determine subcooling level

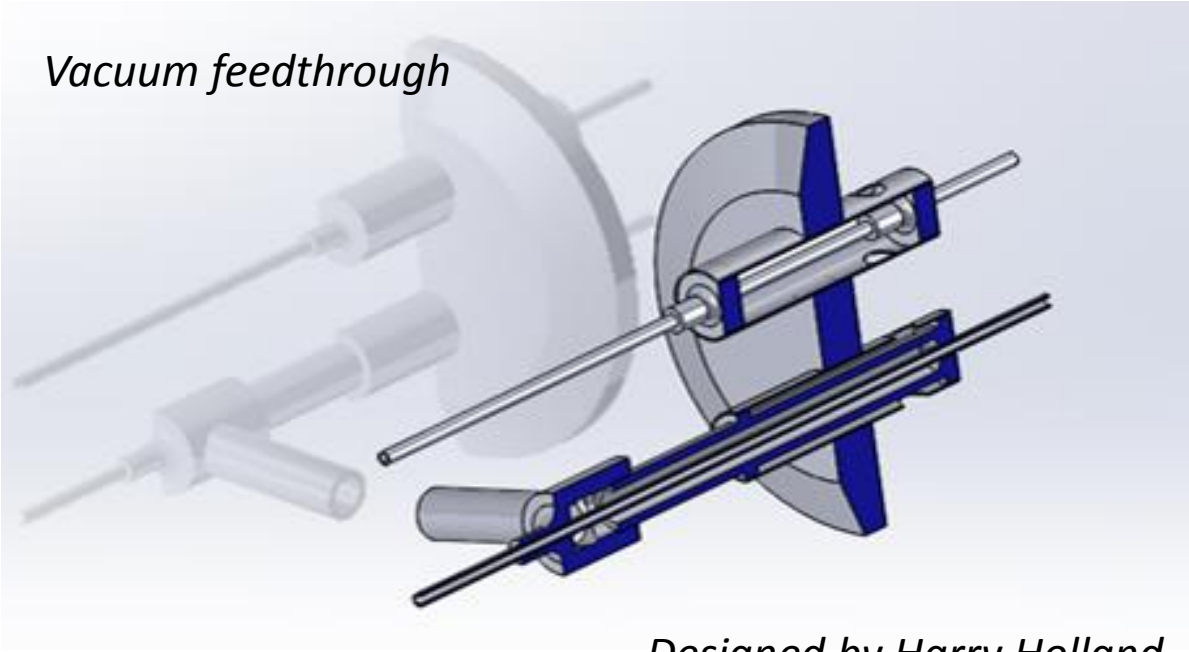
Set-up

- By-pass
- Absolute pressure at inlet
- Differential pressure between inlet and outlet
- Pressure controller valve for the test section
- Mass flow (total and in the test section) with Coriolis flow meters, M13 mini-Coriolis Bronkorst and RHE015 Rheonik
- Thermocouples type K for blow system, E for test section
- Vacuum for the test section with glass chamber
- DAQ and signal conditioning
- NI 6259 DAQ and PICO USB-TC08
- Readings accuracy; TC ~ 1.7 ^{o}C, PT1000 ~0.2 ^{o}C, P ~0.5 bar



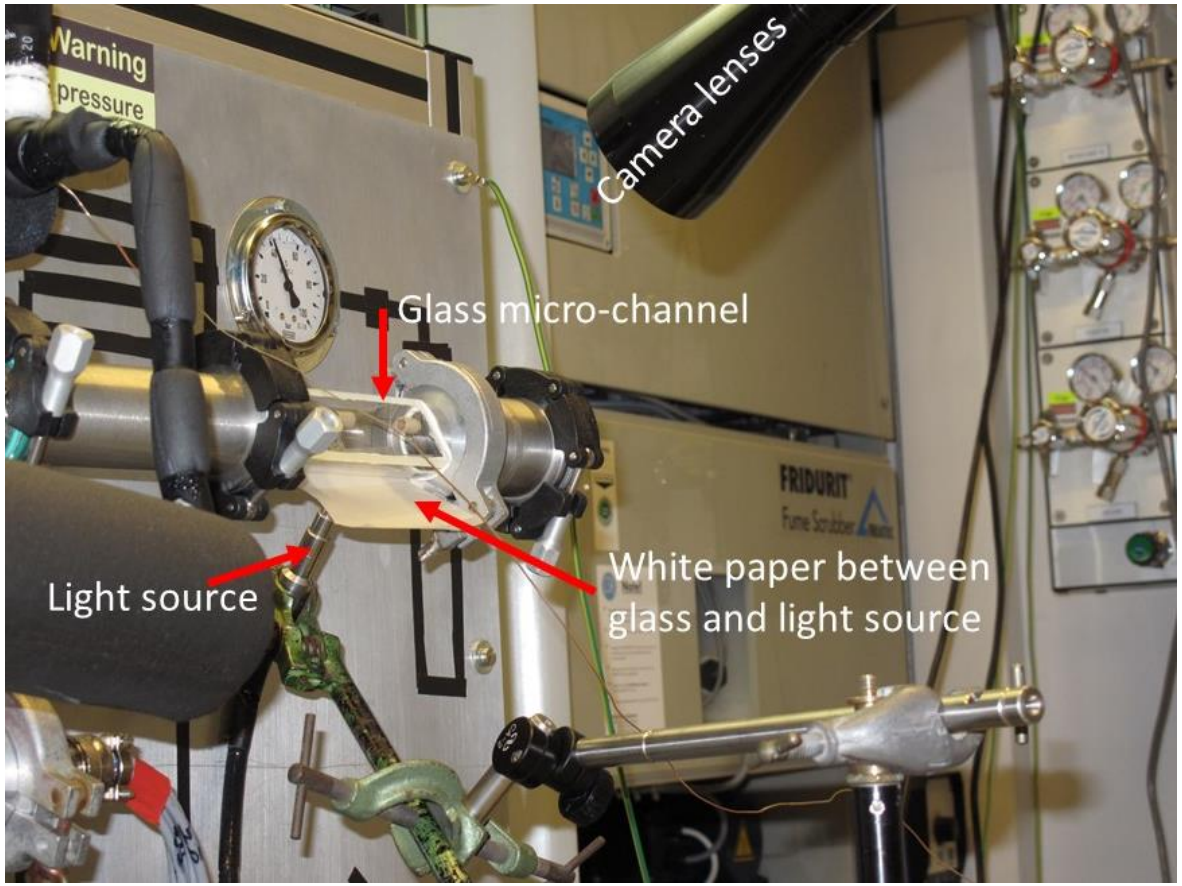
Set-up

Due to increased heat leaks, inlet is cooled further in vacuum feedthrough , tube-in-tube CHFX



Designed by Harry Holland

- High speed camera for flow visualization (FASTCAM SA-X2 Photron)
- Fiber optics bundle Olympo ILP1

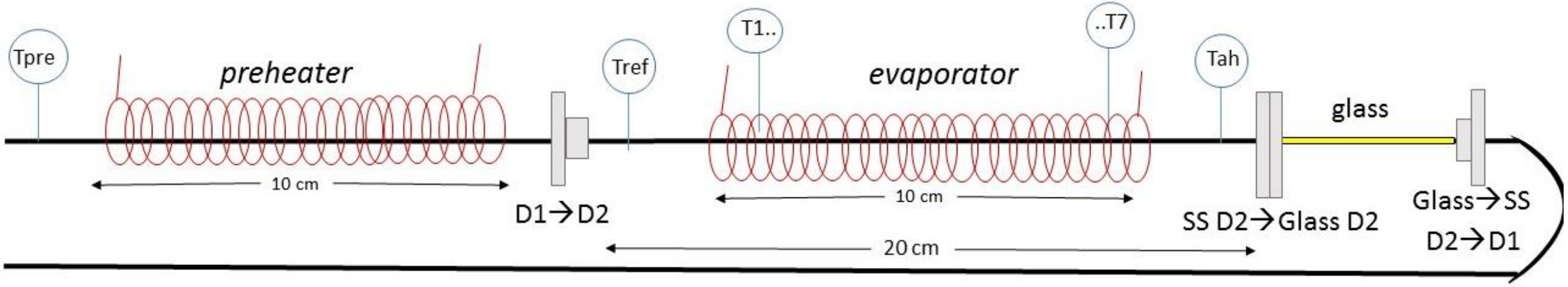


Test section in vacuum- temperatures

- 7 thermocouple type E (OD~ 0.1 mm) between the heater with reference cold junction the T_{ref}
- 2 thermocouple type E before the preheater and after the heater
- 1 PT1000 before the heater = T_{ref}
- Heat sink them on the cooling tube

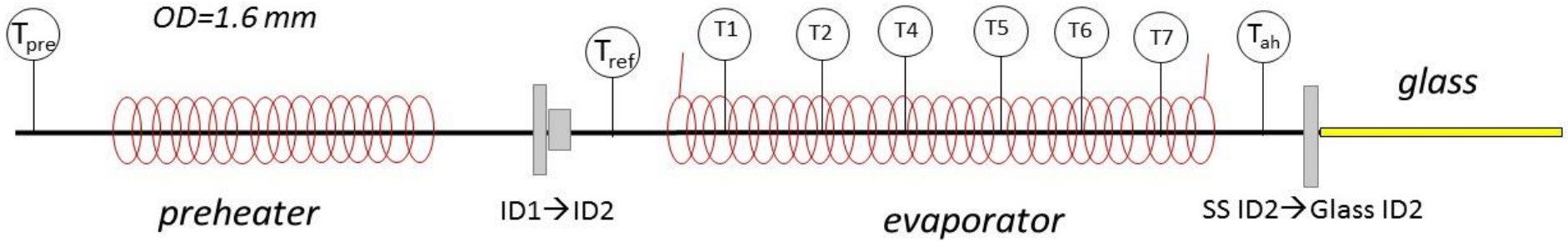
Inner diameter:
ID1=0.88 mm
ID2=0.25 mm
Outer diameter:
OD=1.6 mm

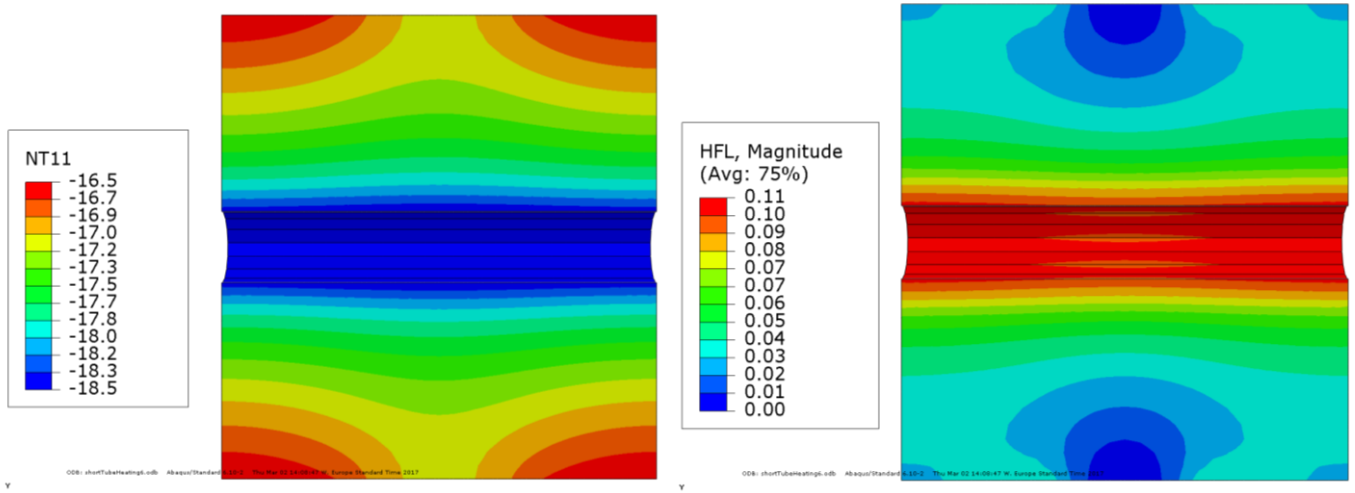
T: Temperature sensor
T_{pre}: before preheater
T_{ah}: after heater
T_{ref}: PT1000



Test section in vacuum- heating

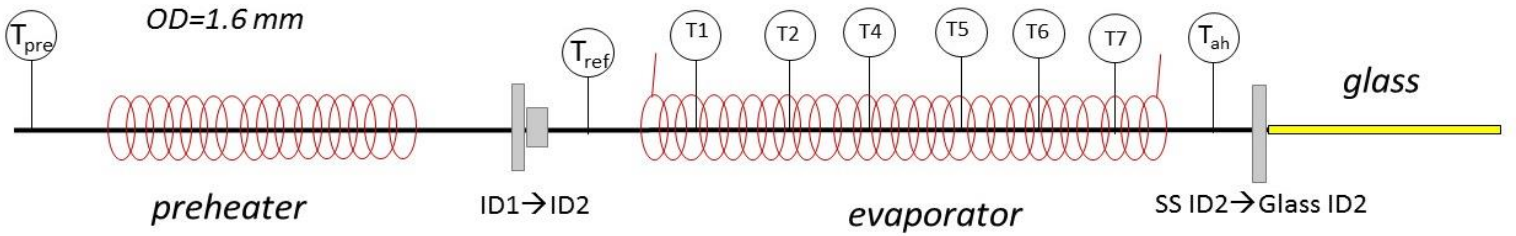
- Heating of the evaporator and preheater with manganine wire
- Analytical and numerical analysis showed no big effect of unheated sections in terms of temperature and heat distribution at the outer and inner wall

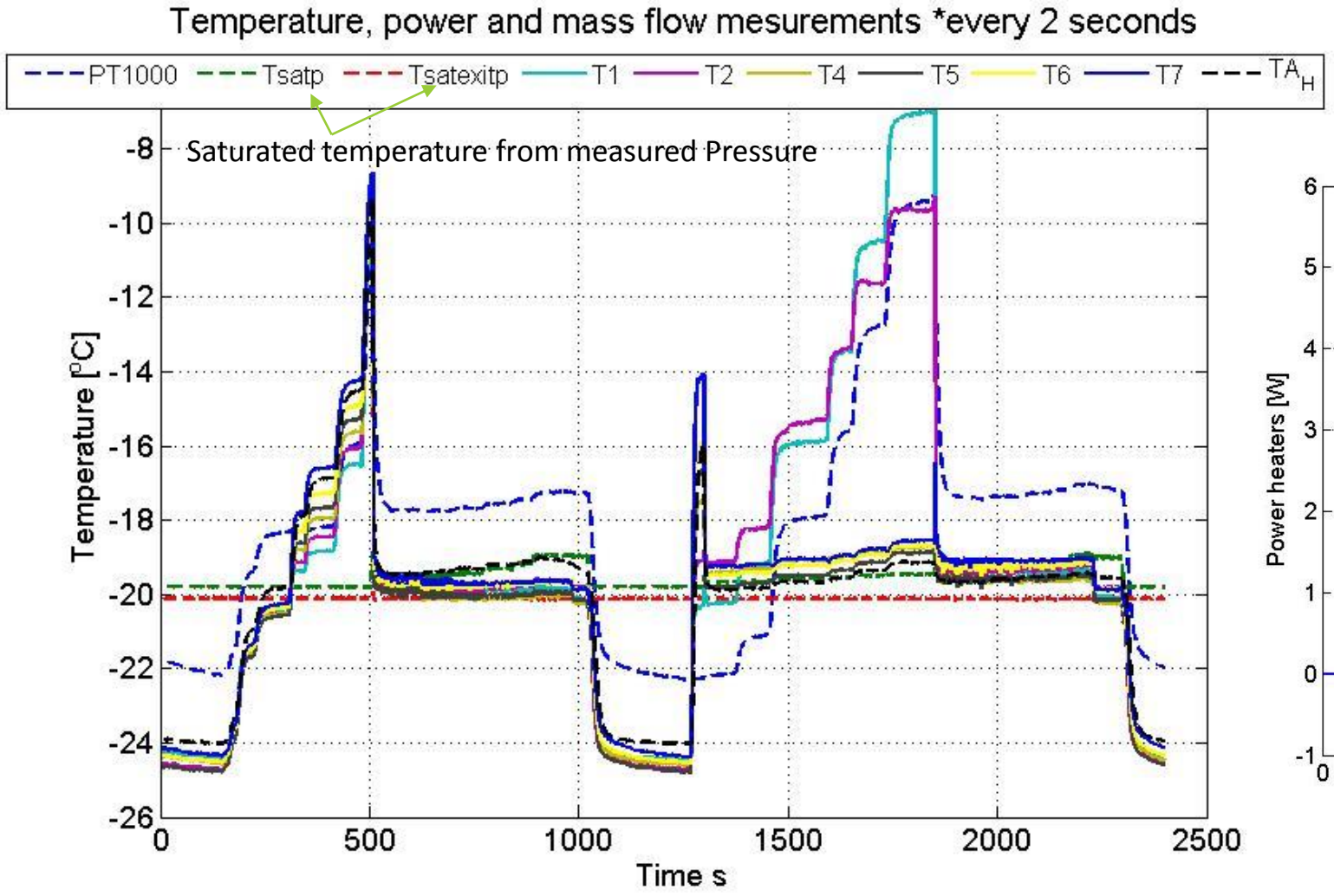




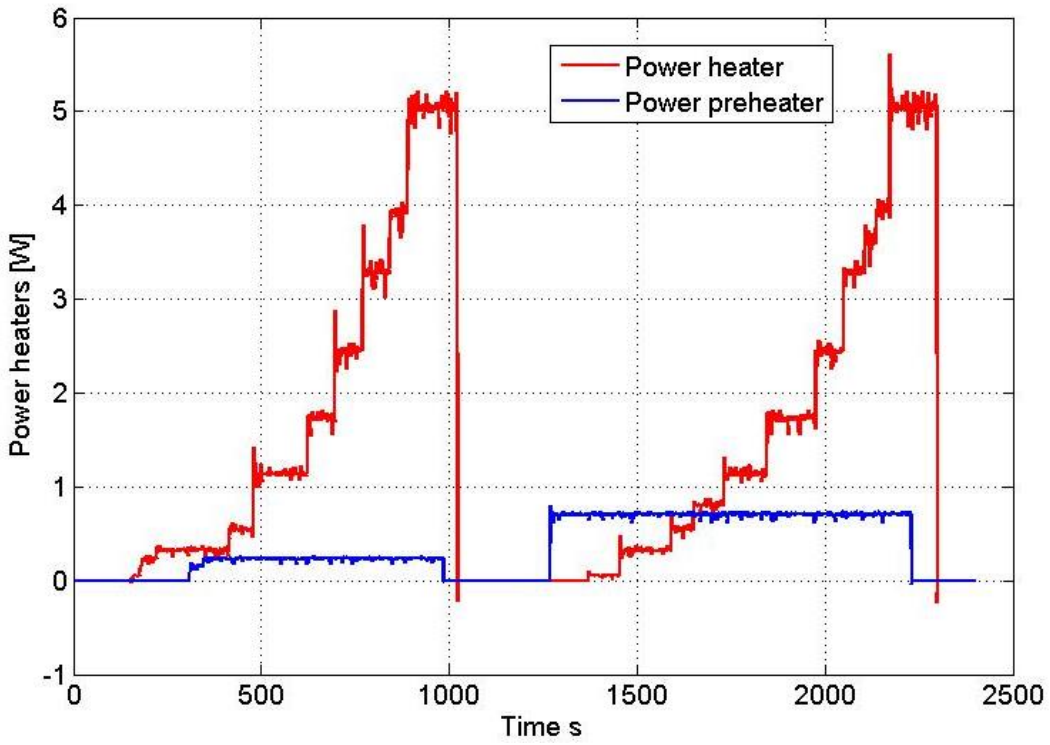
for 0.5 mm heated and unheated space

Measurements single μ-channel

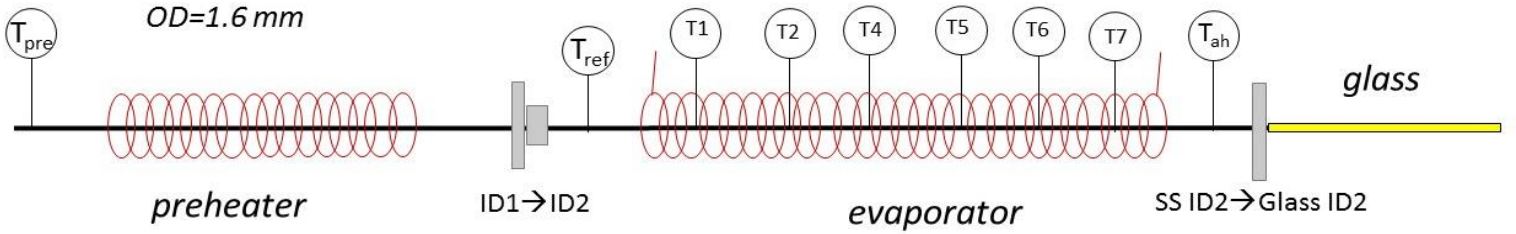


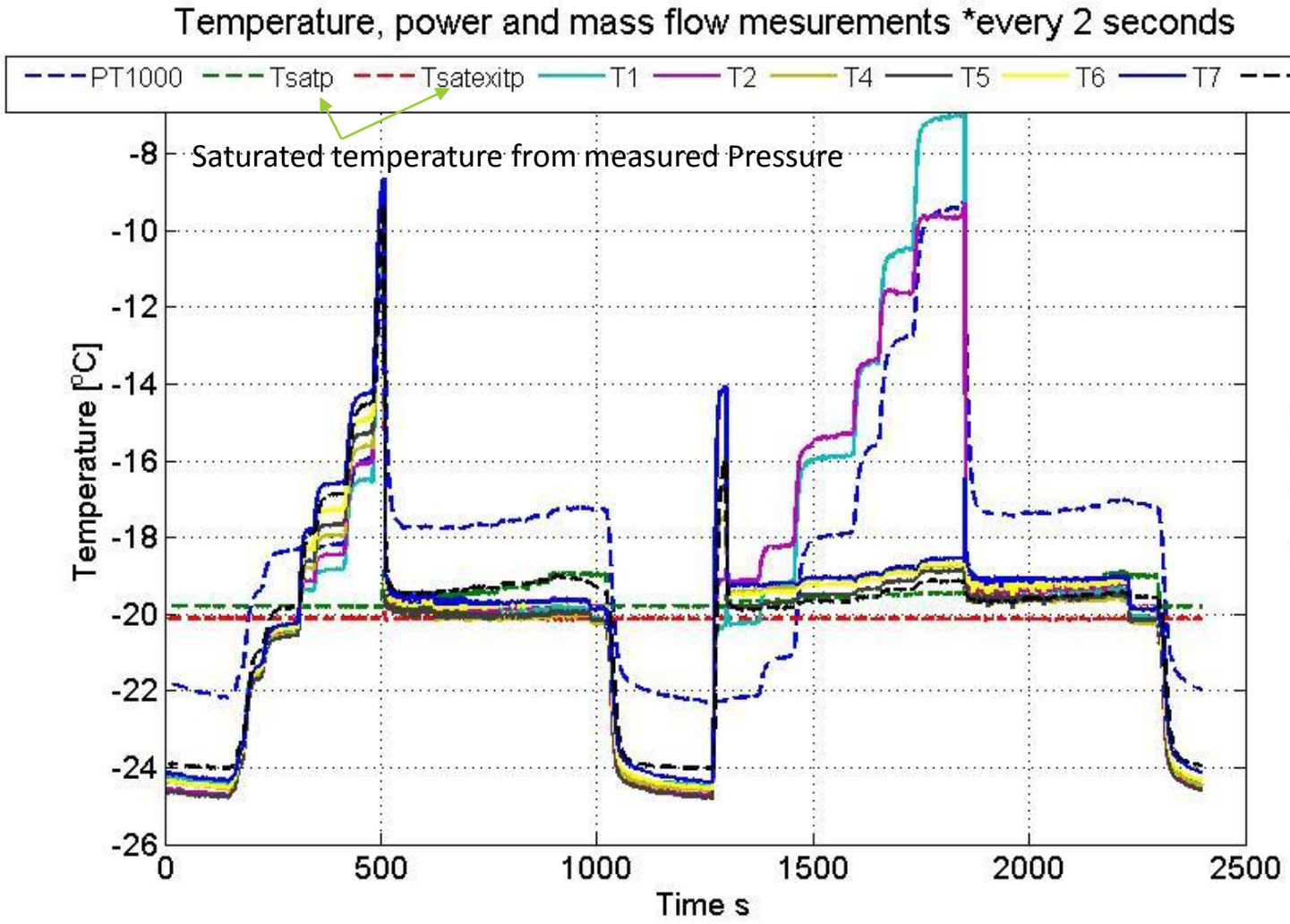


Raw data



Measurements single μ-channel





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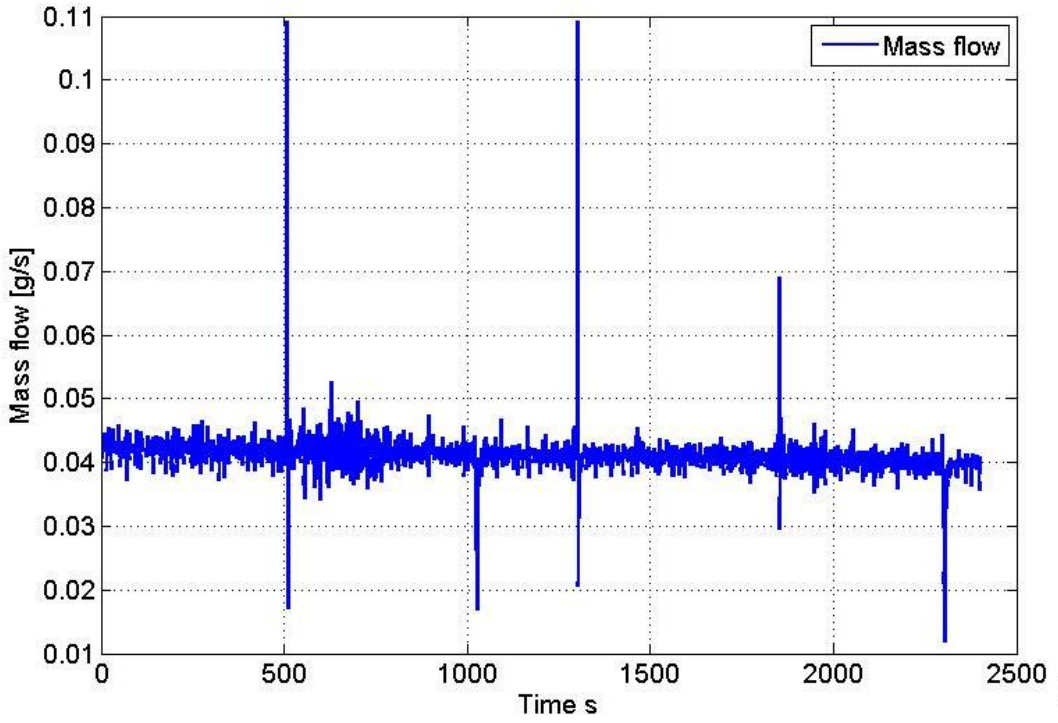
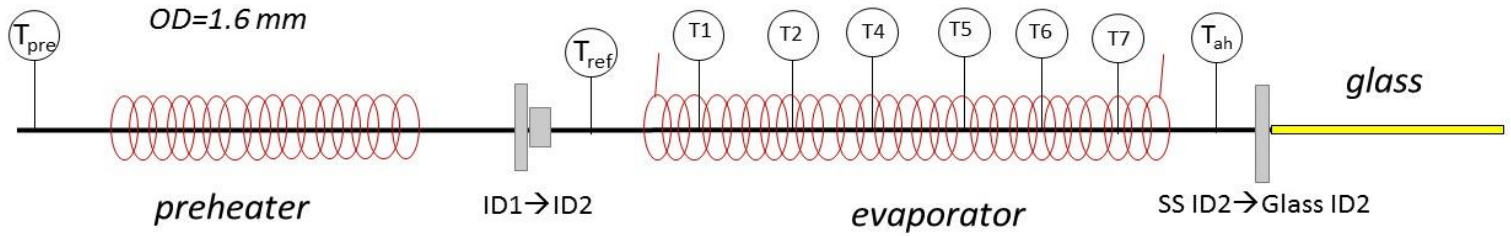
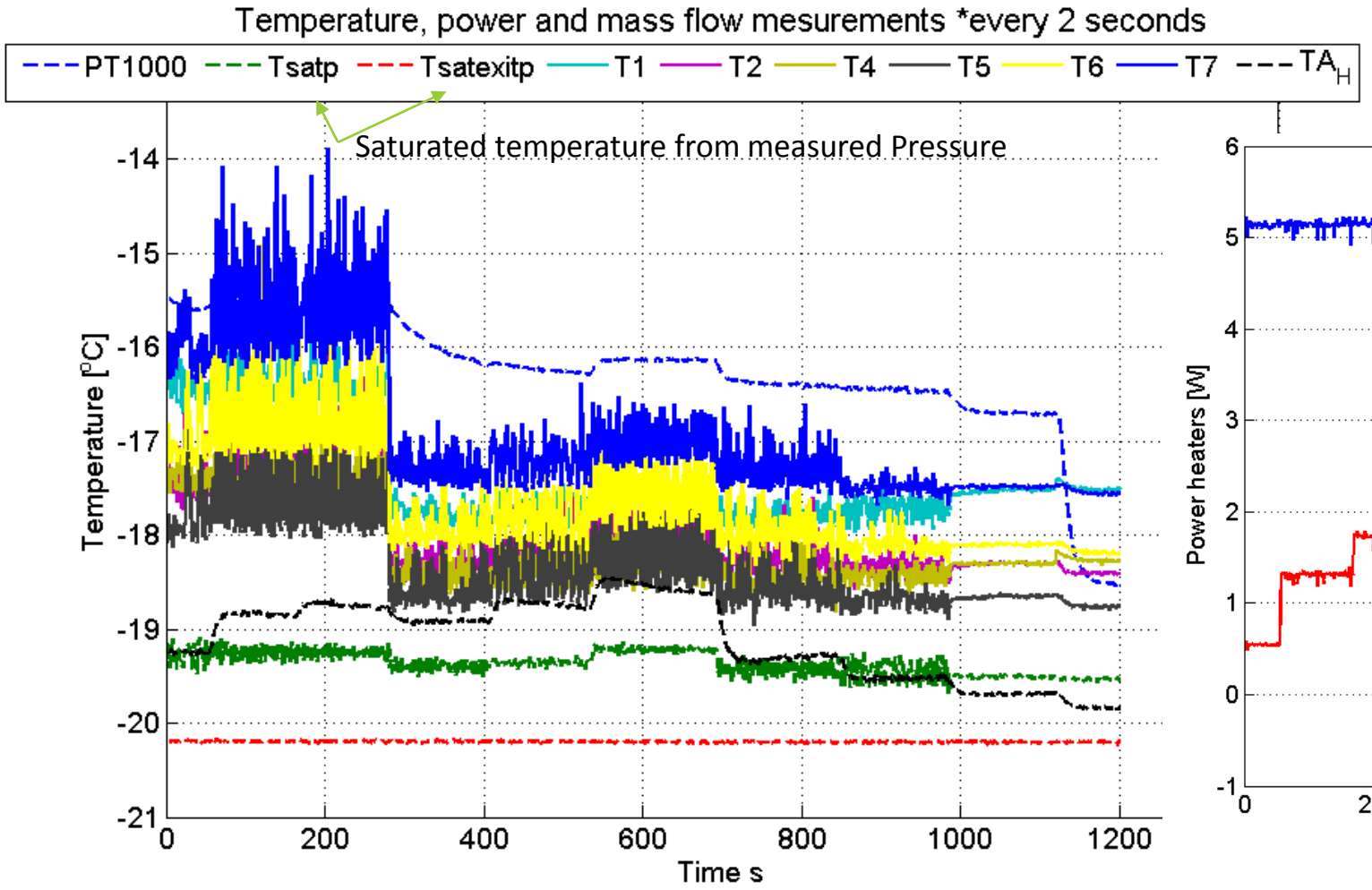


Measurements single μ-channel





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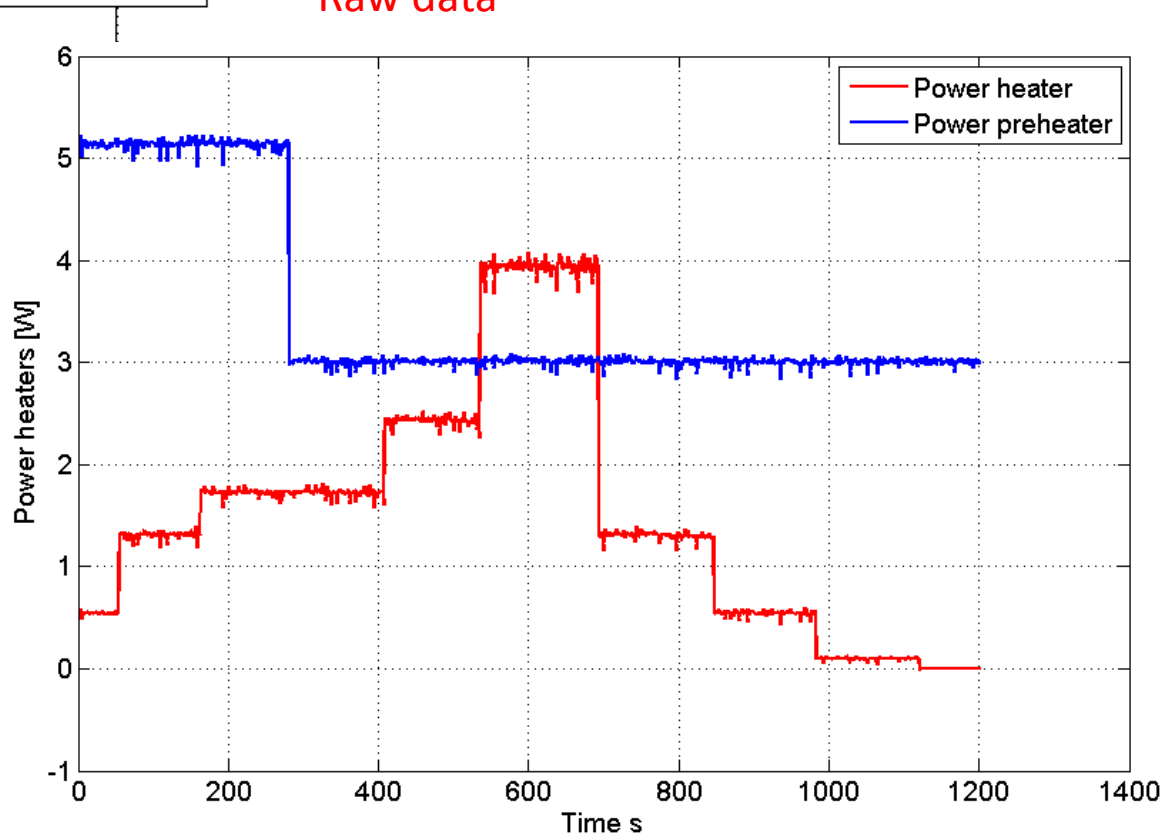
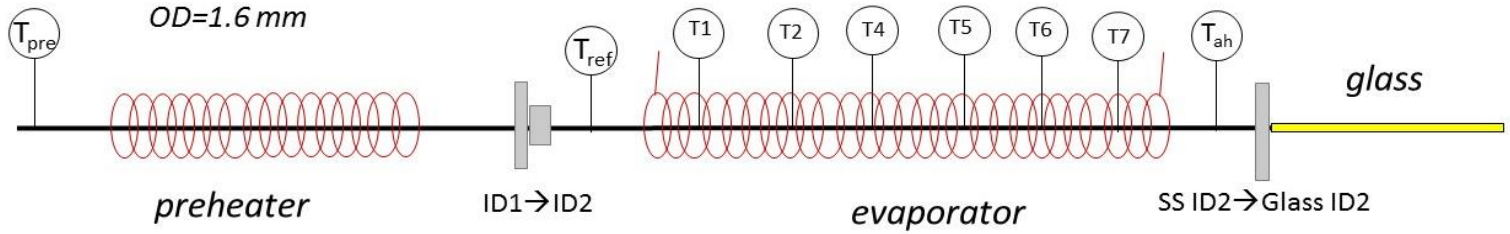


Measurements camera



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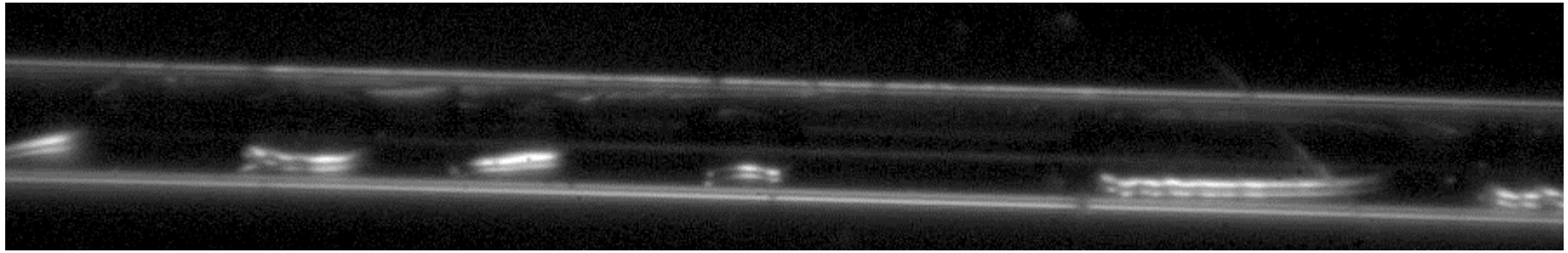
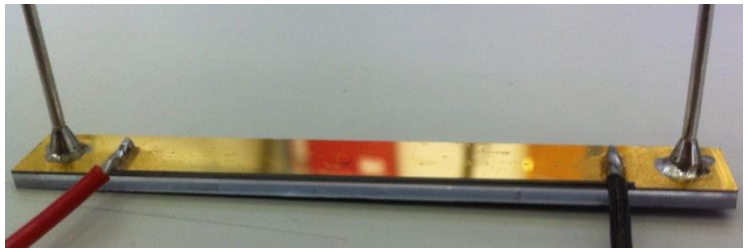
Shutter Speed(s) : 1/50000



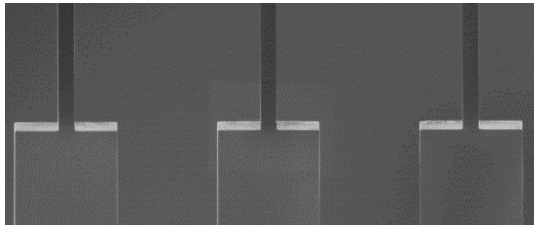
- Completed tests for mass flow range 0.02 -0.1 g/s and power up to 20 W at -20 ^{o}C
- Test section with and without the glass tube

Slide from Forum on Tracking Detector Mechanics 2015 – Amsterdam- by Paolo Petagna



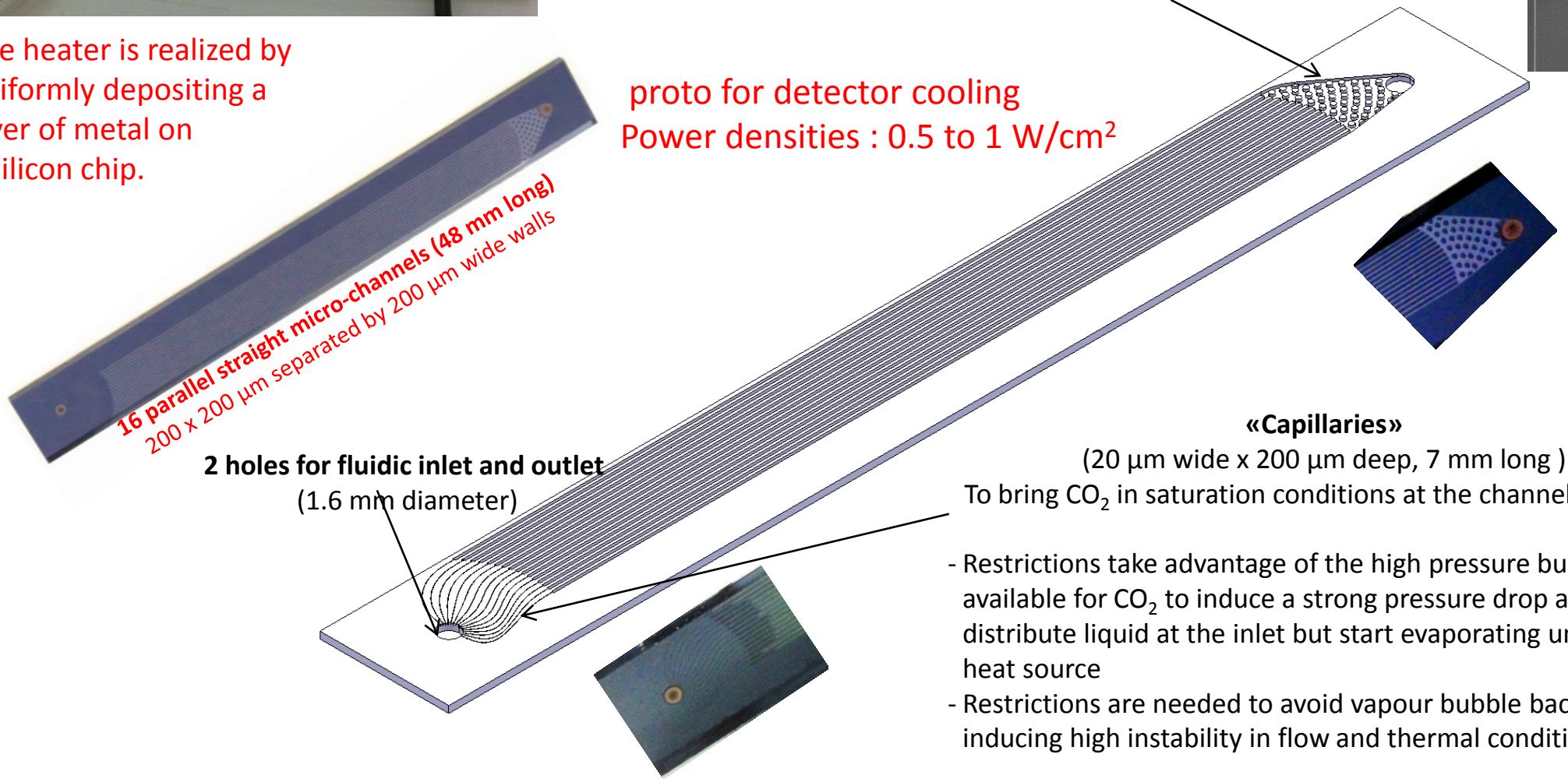
The heater is realized by uniformly depositing a layer of metal on a silicon chip.

Detail of the transition between “capillaries” and “channels”



Pillars in the outlet
to maximize the bonded surface

proto for detector cooling
Power densities : 0.5 to 1 W/cm^2



2 holes for fluidic inlet and outlet
(1.6 mm diameter)

«Capillaries»
(20 µm wide x 200 µm deep, 7 mm long)
To bring CO_2 in saturation conditions at the channel entrance

- Restrictions take advantage of the high pressure budget available for CO_2 to induce a strong pressure drop and to distribute liquid at the inlet but start evaporating under the heat source
- Restrictions are needed to avoid vapour bubble back-flow, inducing high instability in flow and thermal conditions

Device design and fabrication:

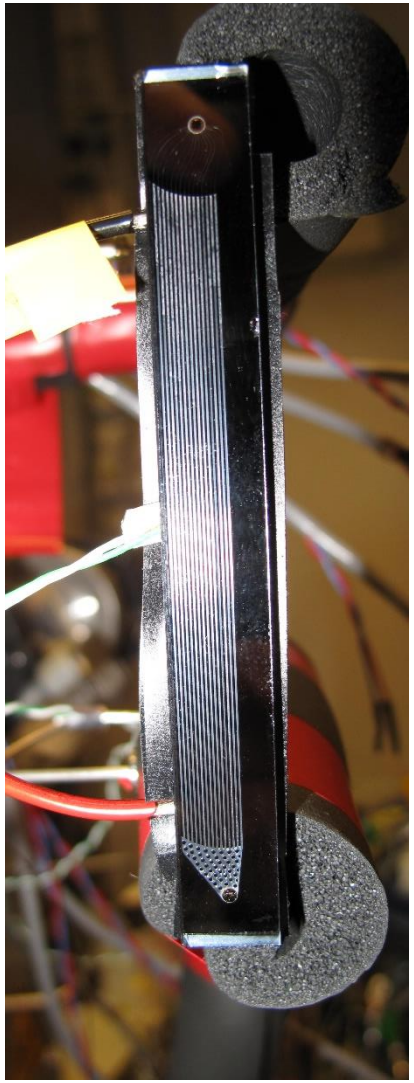
Sequence of testing:

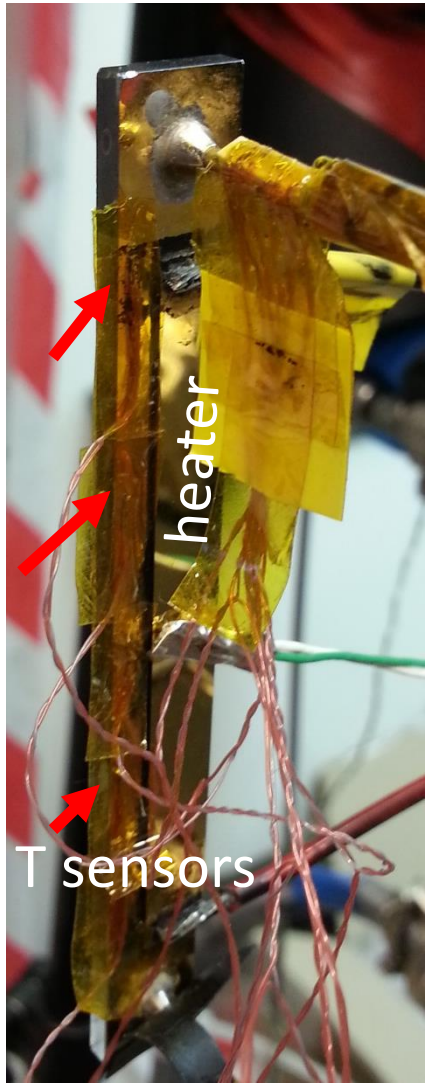
Preliminary tests
Si/pyrex multi μ-channels

- Measure temperatures at inlet/outlet in contact with the fluid
- Measure temperatures along the silicon

Back side with heater

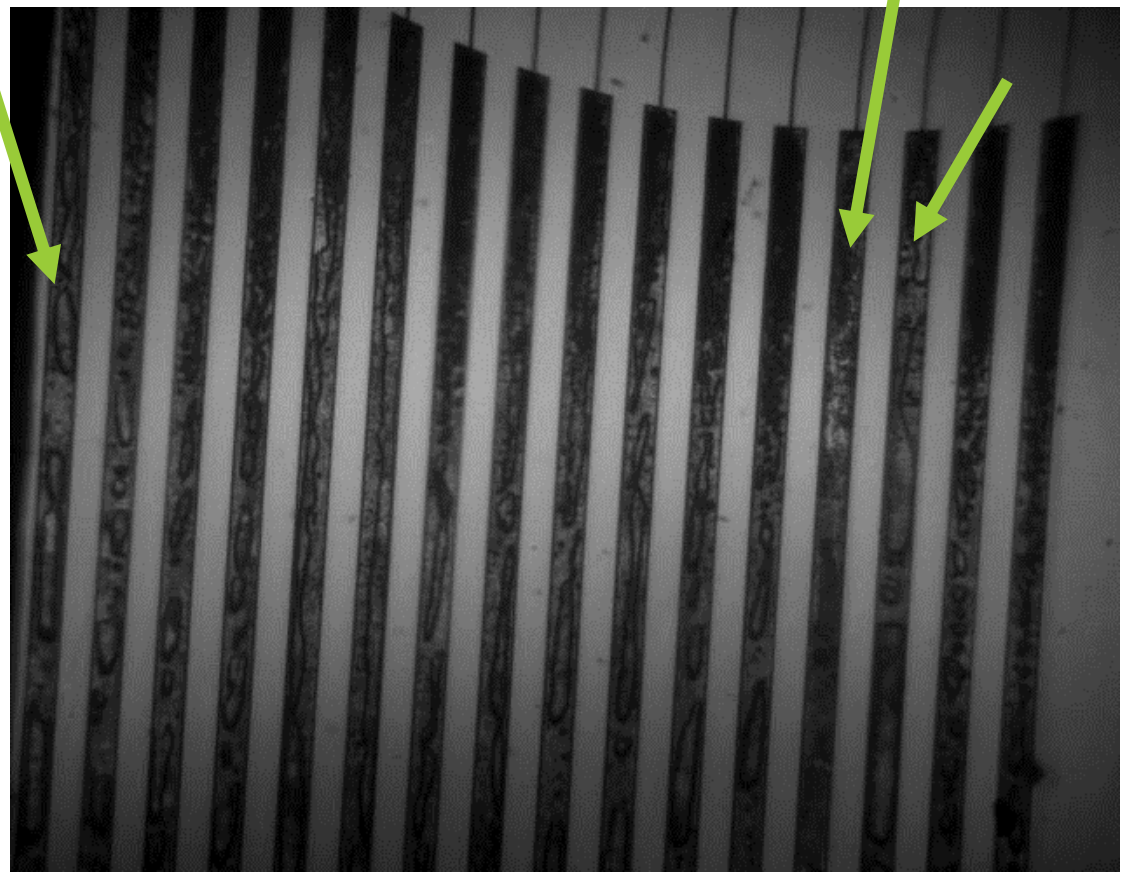
- First tests already – with camera
- One of the channels was clogged; very small capillaries
- The flow wasn't uniformly distributed
- Different velocities





Preliminary tests
Si/pyrex multi μ-channels

Record Rate(fps) : 30000
Shutter Speed(s) : 1/200000



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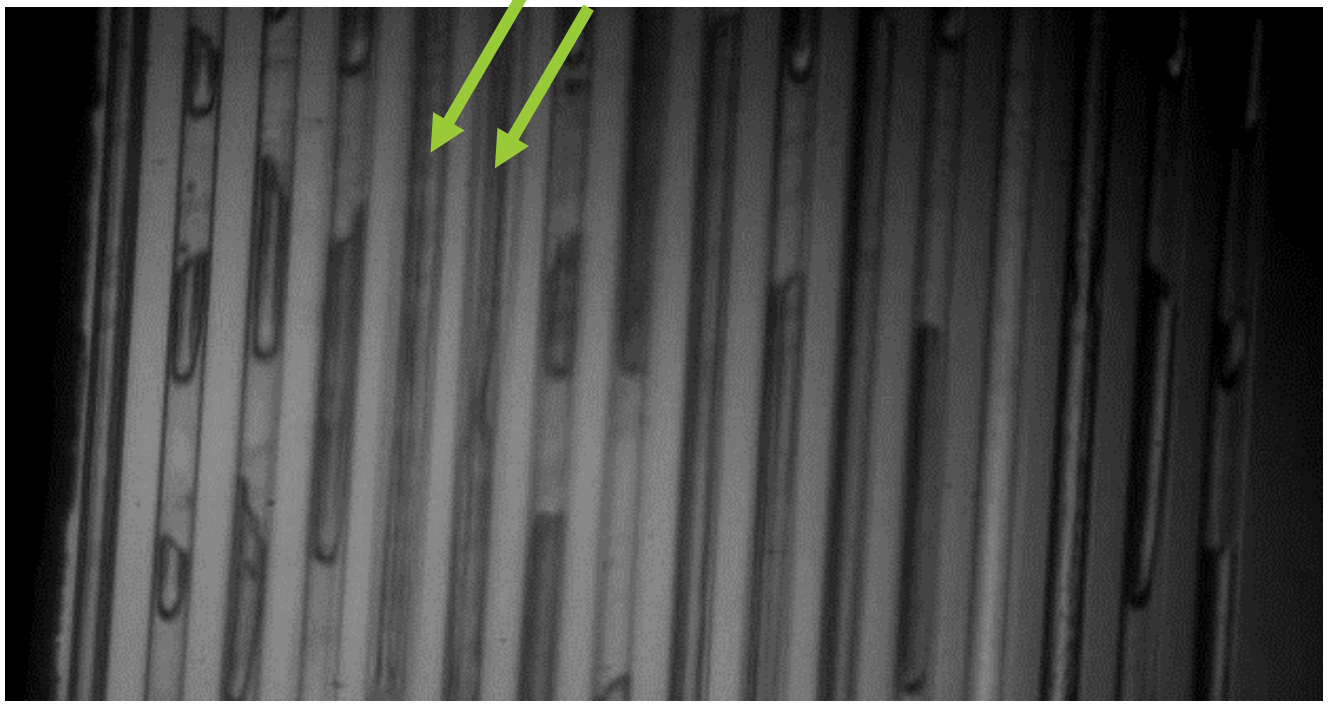
Shutter Speed(s) : 1/266666



Future plans

- Focus on the si/pyrex
- Complete the analysis and compare with prediction models
- Publish paper on first results for single channel

AIDA 2020

Thank you!

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