New CERN CO_2 Test Facility for Mini- and Micro-channels

WP 9 - D9.1

AIDA Annual Meeting
Paris

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EP-DT-FS
CERN, Geneva, Switzerland

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OVERVIEW

- Motivation
- Approach
- Test facility
- Research plan
- Conclusion

MOTIVATION

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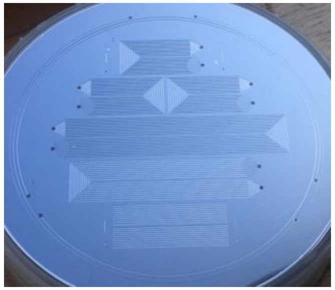
MPG HLL HALBLEITERLABOR DER MAX-PLANCK-GESELLSCHAFT



FONDAZIONE BRUNO KESSLER

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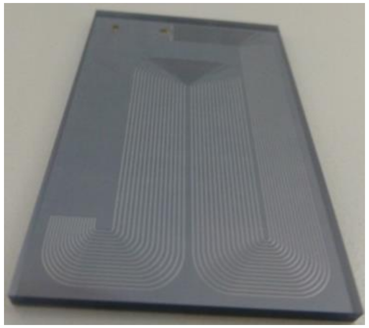
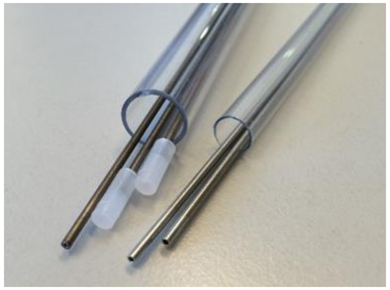


REQUIRED:
Internal standard to test μ-channel cooling devices



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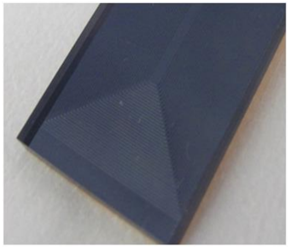
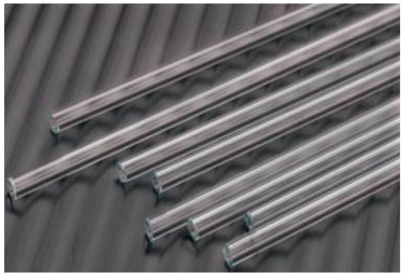


MANCHESTER 1824
The University of Manchester



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MOTIVATION

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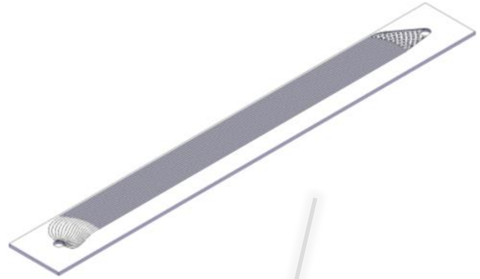

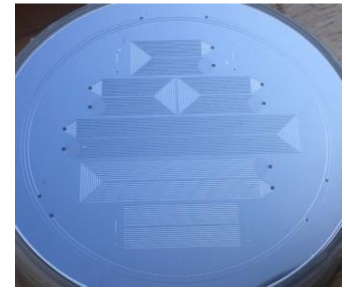

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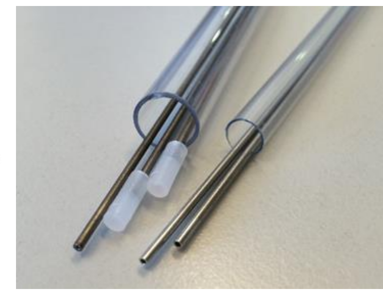
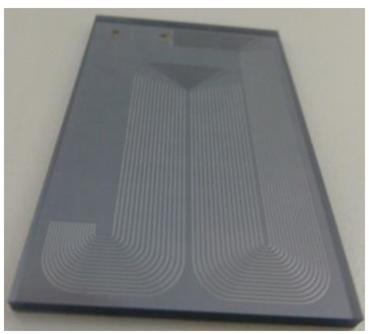
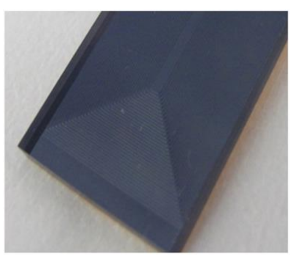
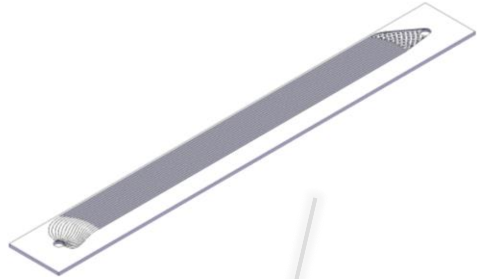
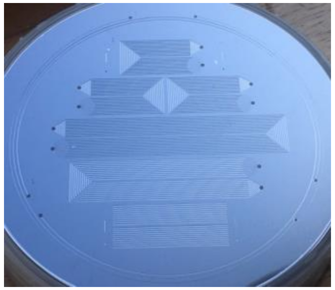




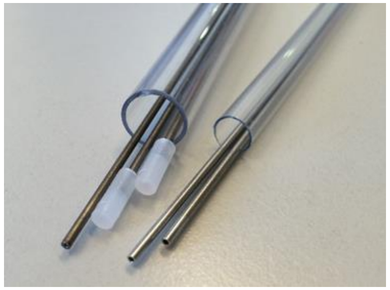
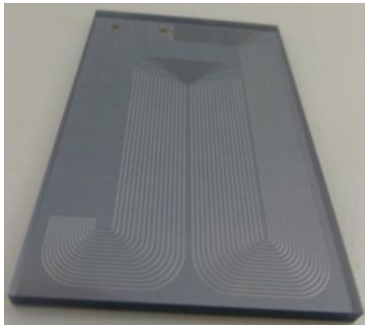
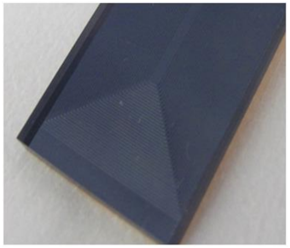
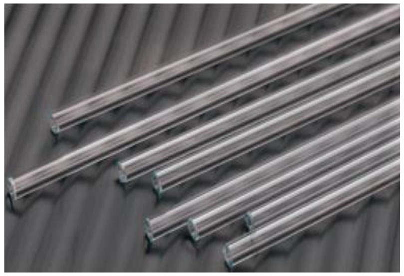


MOTIVATION

MAIN OBJECTIVE:

Characterization of **thermal properties** and **pressure drop** behavior of µ-channel cooling devices

APPROACH

Definition of **common needs** for the institutes

BALANCE

Resources available at CERN

Definition of the ***state-of-the-art*** test stand

BALANCE

active **re-definition** of a

high quality test stand

Common parameters of interest

- mass flux
- fluid pressure
- fluid temperature
- heat dissipation
- pressure drop

Fig. 1 CO_2 refrigeration apparatus at CERN

Resources available at CERN

- evaporative CO_2 is the chosen refrigerant
- **T**ransportable **R**efrigeration **A**pparatus for **C**O_2 **I**nvestigation = **TRACI** developed at CERN
  - CO_2 is an eco-friendly alternative
  - mass flux is adjustable (by-passing)
  - temperature range from ~ +20 to -25℃
  - CO_2 is re-circulated

APPROACH

State-of-the-art **test stand** | **extended version**

Parameters under test	Method
Fluid flow properties	DIRECT: Flow visualization with high speed camera
	INDIRECT: Temperature & pressure sensors
Heat transfer	DIRECT: Temperature measurements in the flow and on surrounding equipment
	INDIRECT: Heat transfer visualization with infrared camera
Pressure drop	Absolute & relative pressure transducers

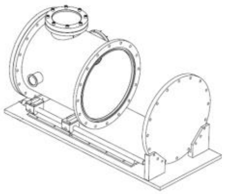
APPROACH

More controlled measurement surroundings are ensured by following components:

2-phase CO_2

Transportable Refrigeration Apparatus for CO_2 Investigation

Vacuum vessel



Adiabatic test conditions for more accurate heat transfer measurements

P & T sensors

High precision measurements for pressure & heat transfer

Flow meter

Direct high precision measurement of the mass flow rate

IR Camera

Heat transfer visualization

High speed cam

Visualization of details on bubble dynamics (100 000 fps)

+ Data acquisition

TEST FACILITY

pressure and temperature sensors before and after the experiment (Measurement points = MP1 to MP4)

temperature sensors on the experiment

two Peltier elements as pre- and post-heater

Mock-up heater (Joule Heater)

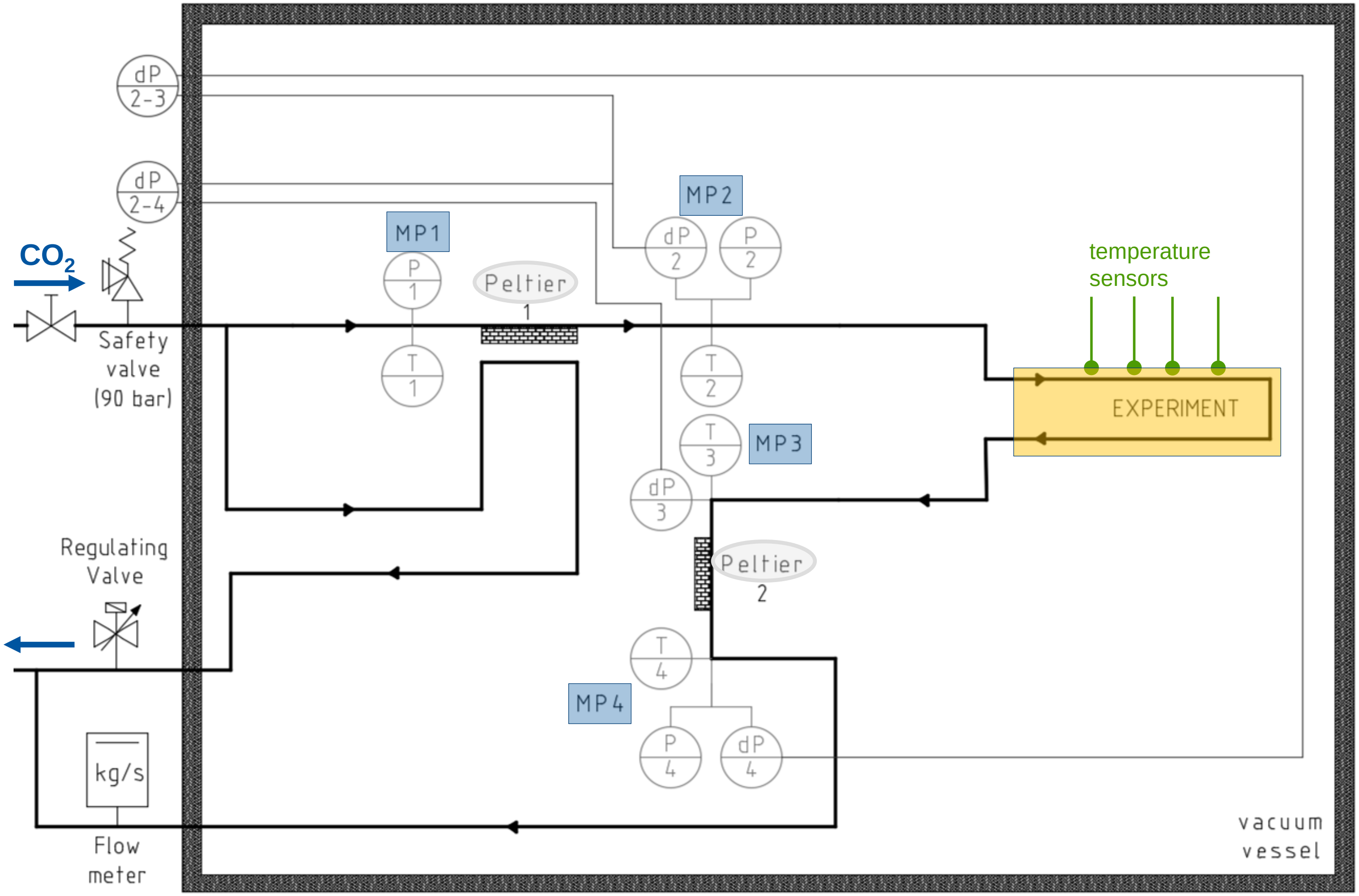


Fig. 2 Schematic of the new CO_2 test facility

TEST FACILITY

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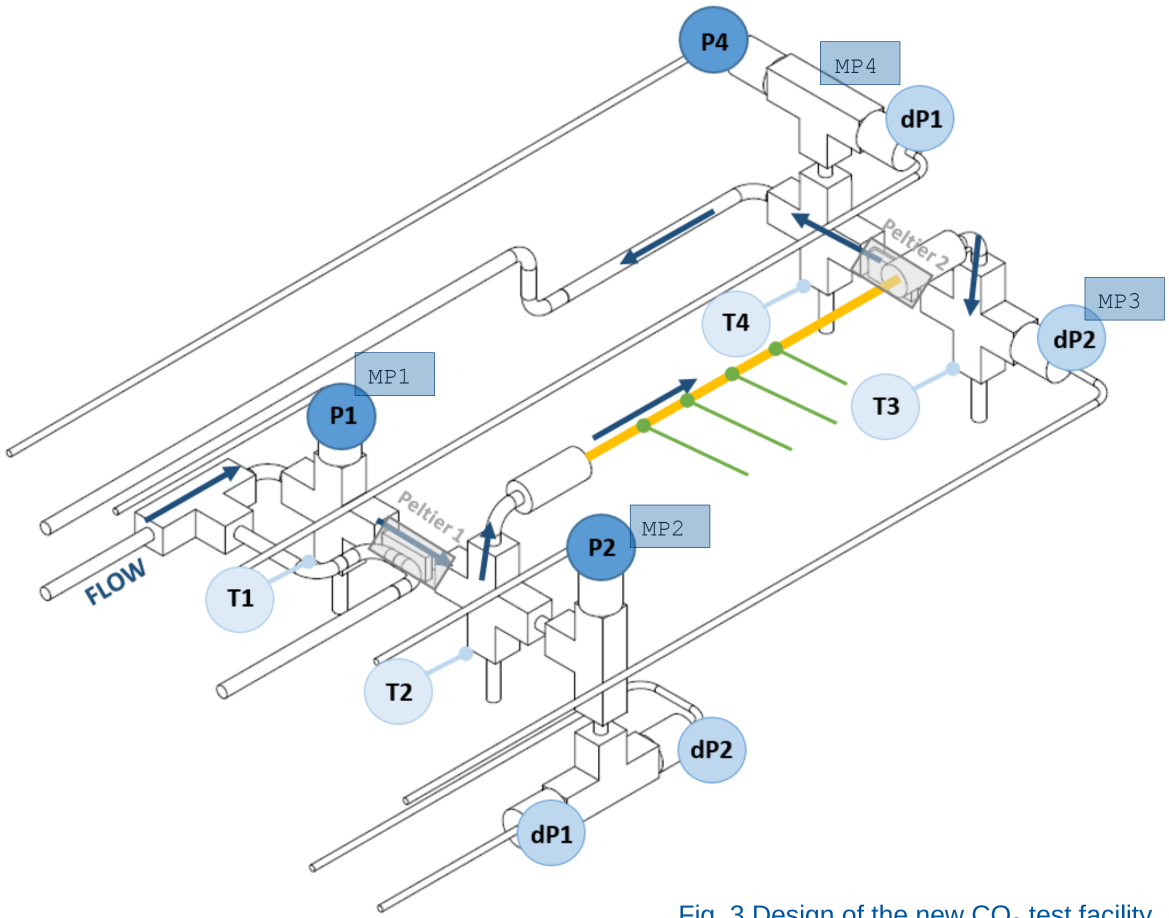


Fig. 3 Design of the new CO_2 test facility

TEST FACILITY

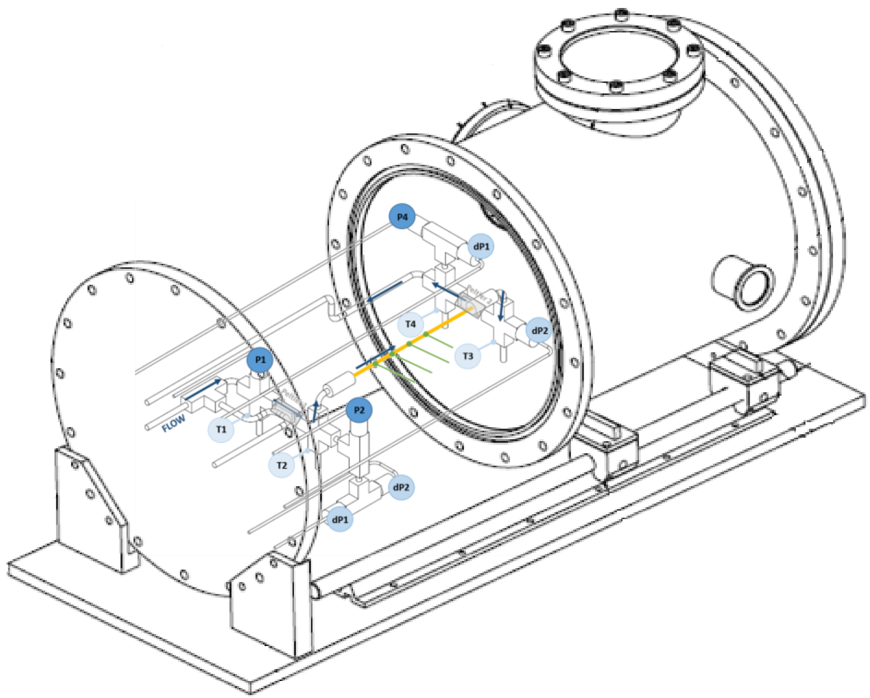


Fig. 4 Schematic of the new CO_2 test facility with vacuum vessel

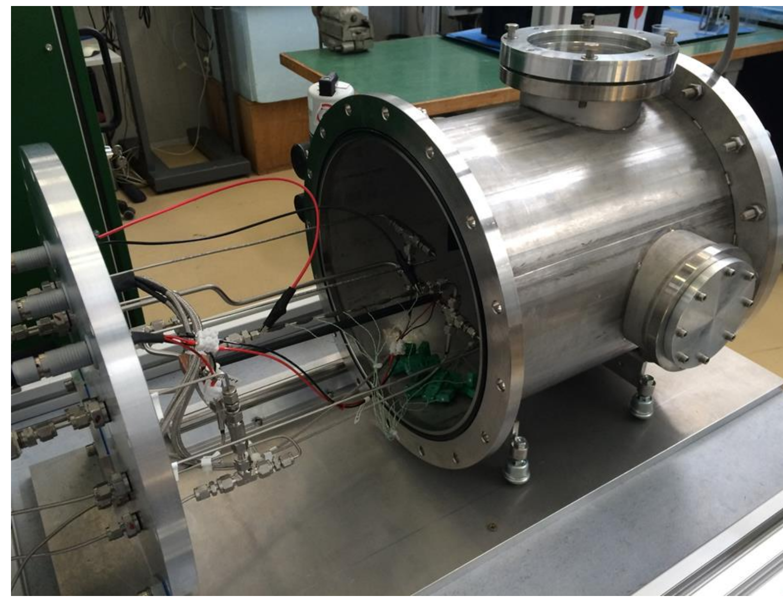
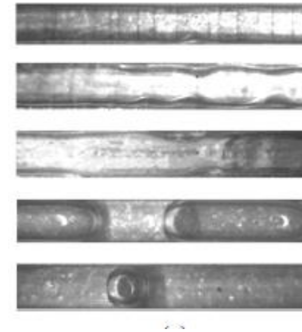
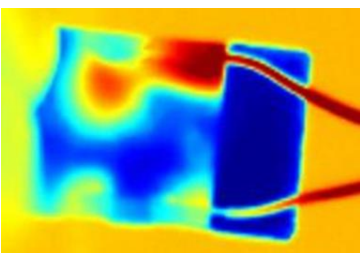


Fig. 5 Experiment section and vacuum vessel of the new CO_2 test facility

TEST FACILITY

HIGH SPEED CAMERA





INFRA-RED CAMERA

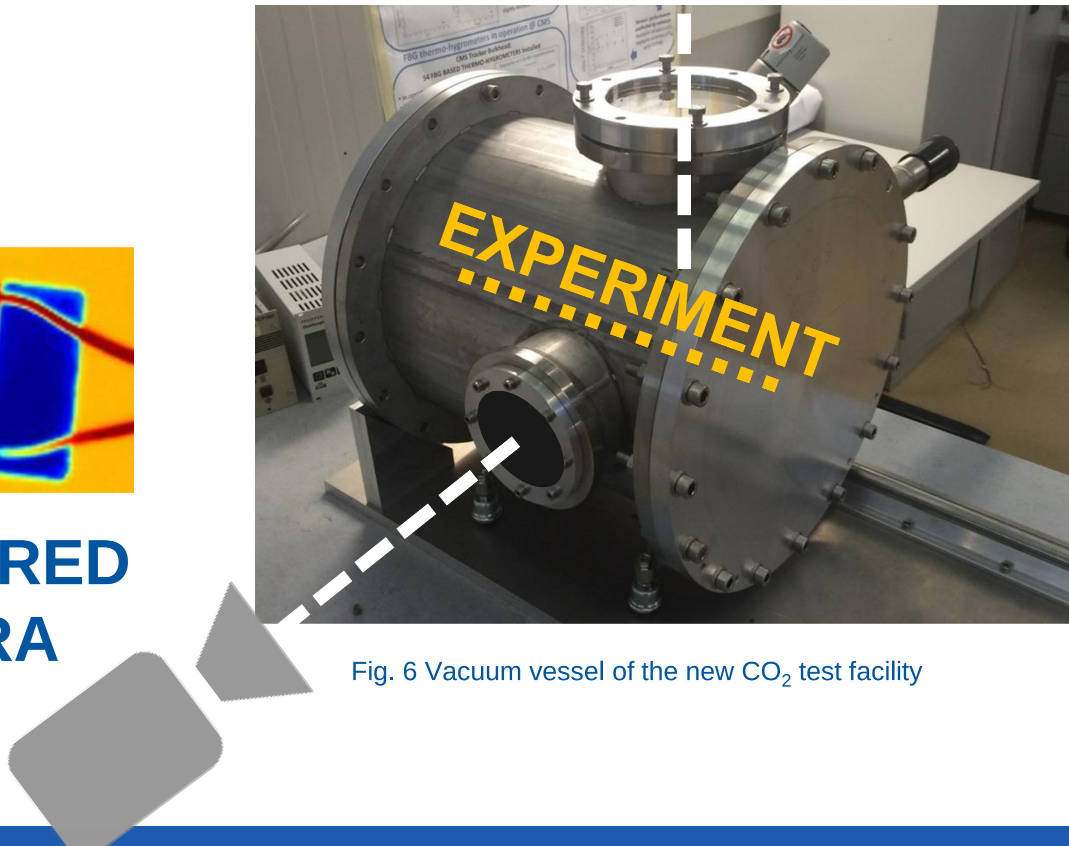


Fig. 6 Vacuum vessel of the new CO_2 test facility

TEST FACILITY

Fig. 7 New test facility for evaporative CO_2 flow measurements in mini- and micro-channels (I)

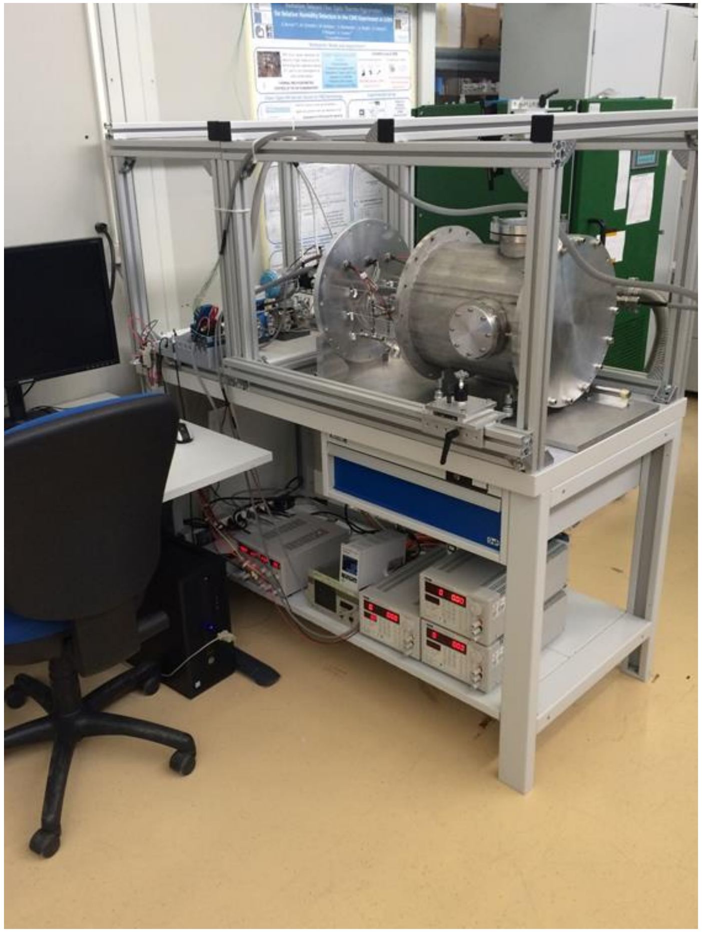


Fig. 8 New test facility for evaporative CO_2 flow measurements in mini- and micro-channels (II)

TEST FACILITY

Fig. 9 Differential & absolute pressure sensors and flow meter outside the vacuum vessel

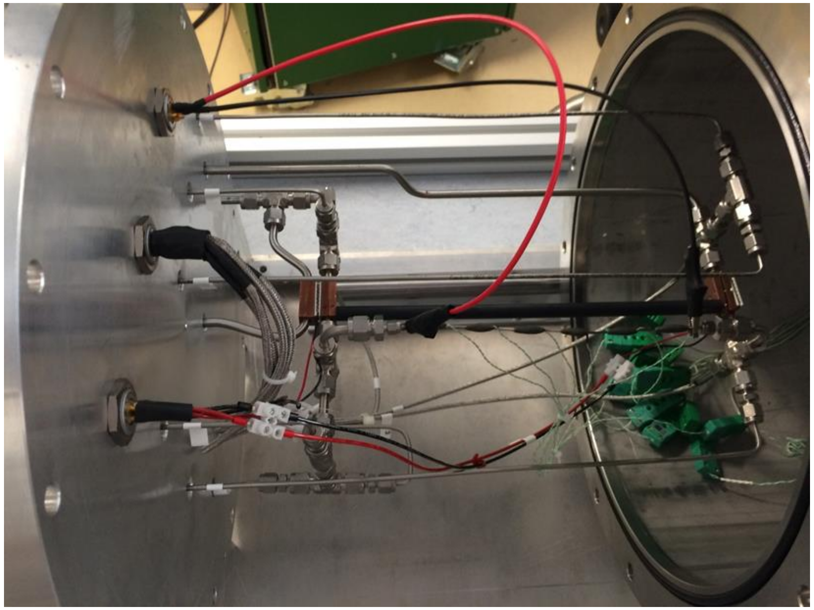


Fig. 10 Experiment section within the vessel

TEST FACILITY

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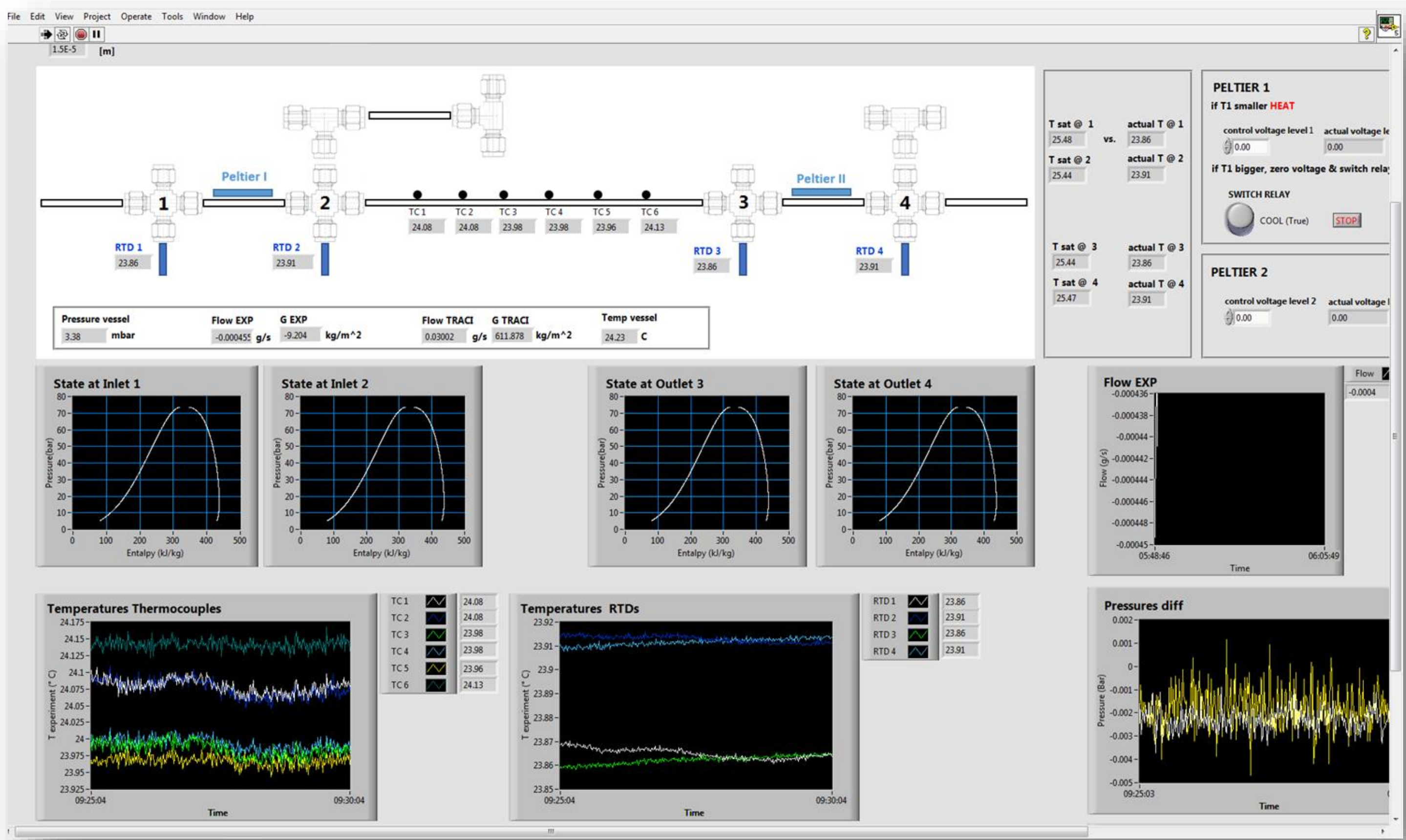
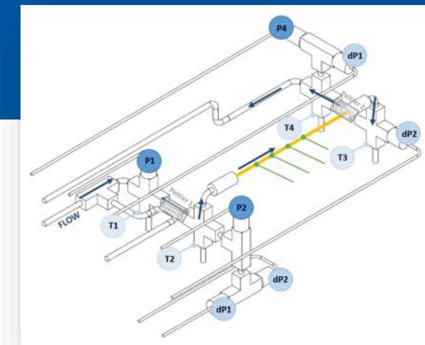
DATA AQUISITION with LabVIEW®

- experiment sensors
- flow meter
- vacuum level
- temperature inside vacuum vessel
- control of Peltier & Joule heater
- online-evaluation of fluid state
- acquisition in parallel with cameras possible

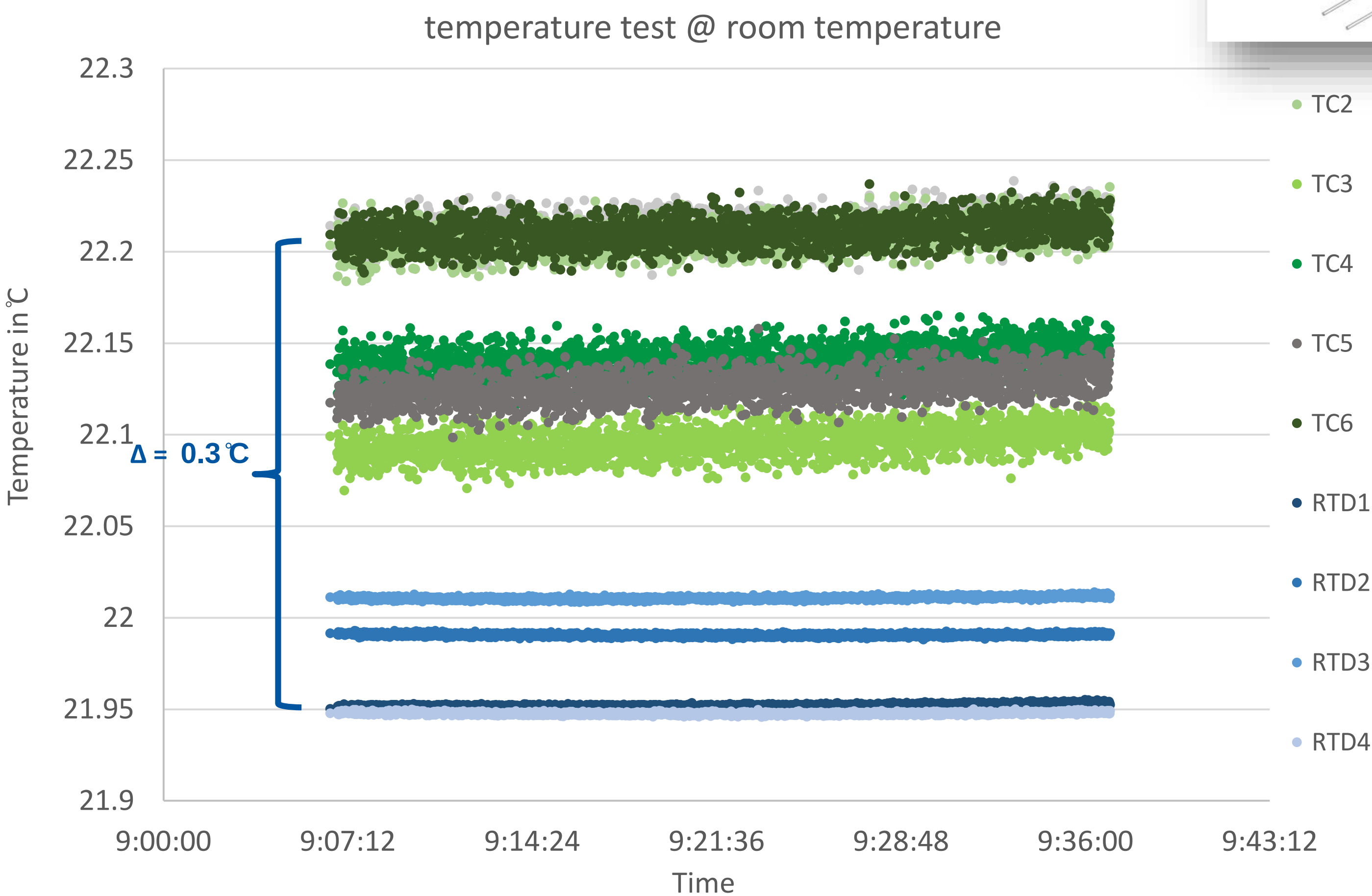


→ MATLAB® code for analysis

TEST FACILITY

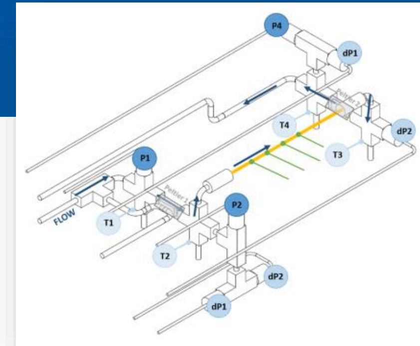


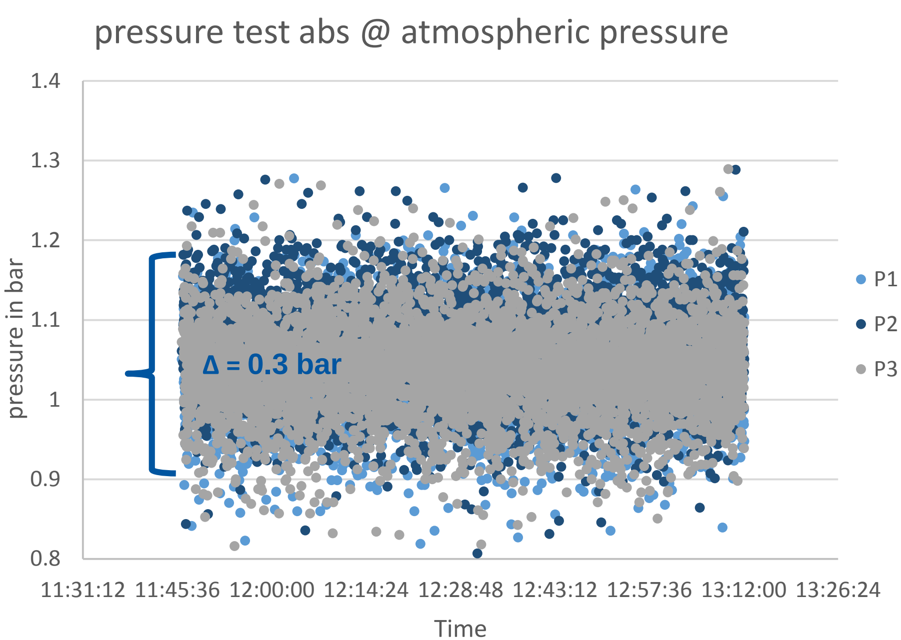
SENSOR CHECK: Temperature

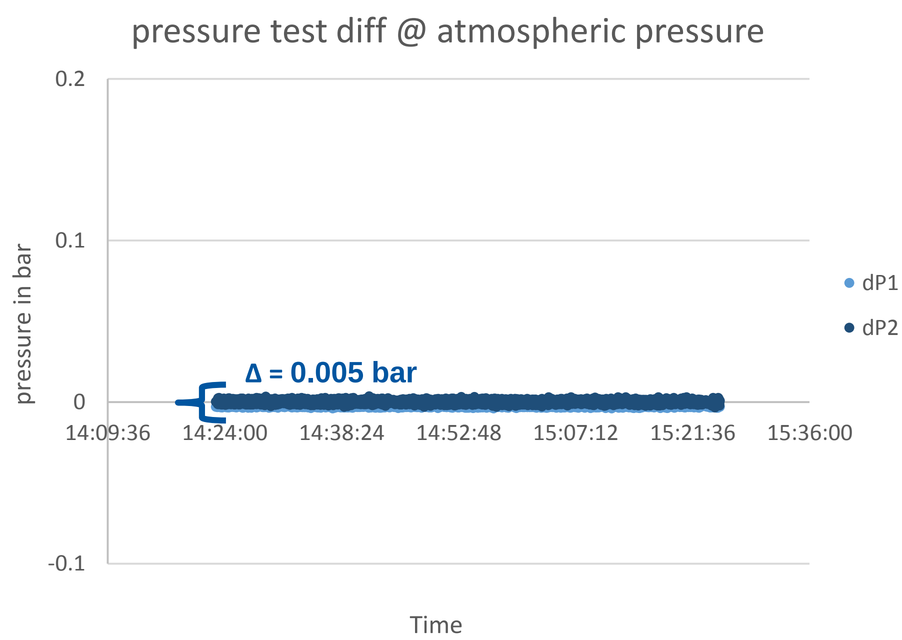


TEST FACILITY

SENSOR CHECK: Pressure







RESEARCH PLAN

GOALS for experimental research on evaporative flow of CO_2 in mini- and micro-channels at CERN:

- Create a **larger and reliable database** for CO_2 pressure drops, heat transfer coefficient and flow patterns in mini- and micro-channels for model upgrades
- **Extend research** towards negative fluid temperatures and micrometer sized channel diameters
- Find and test a theoretical **micro-channel definition**

RESEARCH PLAN

STEP 1 : Test simple single channels / tubes (ID < 2 mm)

To address the complexity of the physical processes occurring in micro-channels and for their better understanding

STEP 2 : Test more complex channel geometries

To address the immediate need for micro-channel cooling in HEP experiments using the gathered insights and results from Step 1

RESEARCH PLAN

STEP 1:

ROUND SINGLE CHANNELS

Stainless Steel

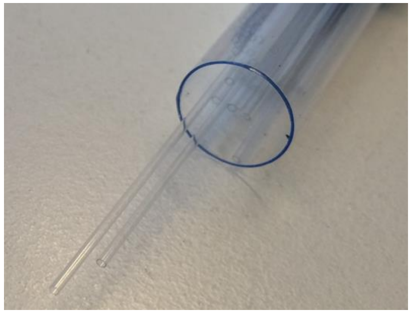
ID [mm]	OD [mm]
0.13	1.58
0.25	1.58
0.5	1.58
0.75	1.58
1	1.58
1.5	3.175
2	3.175

Glass (Borosilicate)

ID [mm]	OD [mm]
0.1	0.17
0.15	0.25
0.2	0.33
0.3	0.4
0.5	0.7
0.7	0.87
0.8	1
1	1.2
1.5	1.8
2	2.4

Titanium

ID [mm]	OD [mm]
0.3	1.58
0.5	1.58
0.8	1.58



SQUARED SINGLE CHANNELS

Glass (Borosilicate)

inner cross-section [mm]	wall thickness [mm]
0.1 x 0.1	0.05
0.8 x 0.8	0.16
0.3 x 0.3	0.15
0.2 x 0.2	0.1
1.0 x 1.0	0.2
0.5 x 0.5	0.1
0.7 x 0.7	0.14

RESEARCH PROPOSALS for STEP 1:

Experimental Thermal and Fluid Science 35 (2011) 581–596

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

journal homepage: www.elsevier.com/locate/etfs

ELSEVIER

Carbon dioxide flow boiling in a single microchannel – Part I: Pressure drops

Maxime Ducoulombier[a,*], Stéphane Colasson[a], Jocelyn Bonjour[b], Philippe Haberschill[b]

Carbon dioxide flow boiling in a single microchannel – Part II: Heat transfer

Maxime Ducoulombier[a,*], Stéphane Colasson[a], Jocelyn Bonjour[b], Philippe Haberschill[b]

Table 2
Experimental conditions and corresponding uncertainties.

	Range	Uncertainty	
		Span	Typical
D_i (μm)	529		5
L_{DP} (mm)	191		0.5
T_{sat} (°C)	−10; −5; 0; 5	0.091; 0.089; 0.088; 0.088	
G (kg/m² s)	200–1400	2.3–1.9%[a]	1.95%
ΔP (mbar)	0–150	0.27–0.45	
	0–1500	2.9–4.5	
x	0–1	1.5 (2.3[b]) to 0.5%[c]	0.85%

[a] Including the uncertainty due to the inner diameter.
[b] Taking into account the maximum uncertainty due to conduction heat leaks, for the lowest mass flux.
[c] Assuming a quality of 1 (unfavourable case); uncertainty mainly depends on mass flux.

VALIDATION PENDING

Micro-channel definition

?

- based on the preliminary work of Y. Moussy
- a possible definition was found
- by means of the bubble departure diameter

$$Def_{\mu} = \mathcal{F}\,(G, \Delta p, T \,...)$$

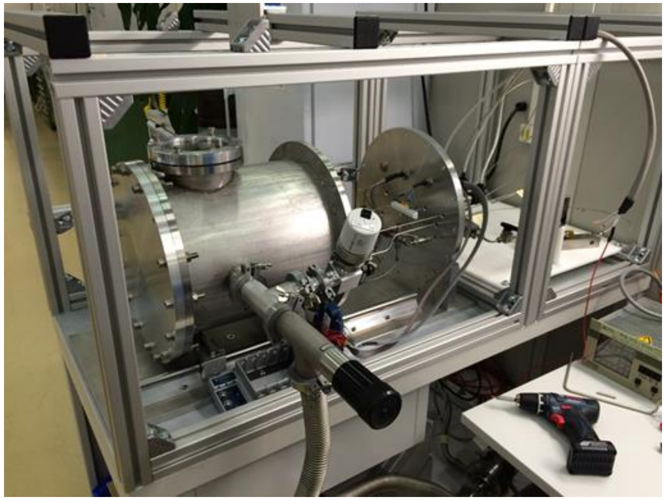
VALIDATION PENDING

CONCLUSION

- ✓ Internal setup to test µ-channel cooling devices is completed
- ✓ Uncertainty level of the experiments can be limited
- ✓ Test stand allows for a wide temperature range
- ✓ CO_2 is an eco-friendly alternative to other refrigerants

- ✓ Component test finished
- ✓ Research program launched for first tests

OUTLOOK



- **Control** the new setup for flow of evaporative CO_2 in μ-channels
- Carry out **measurements**
- **Compare** results with literature
- Use findings for **better understanding** of the physical behaviour of the flow in μ-channels

...

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