Computational Fluid Dynamics (CFD) simulations support to CERN activities

Enrico Da Riva
CERN (EN/CV)

CSEM-CERN Meeting, 23 May 2013

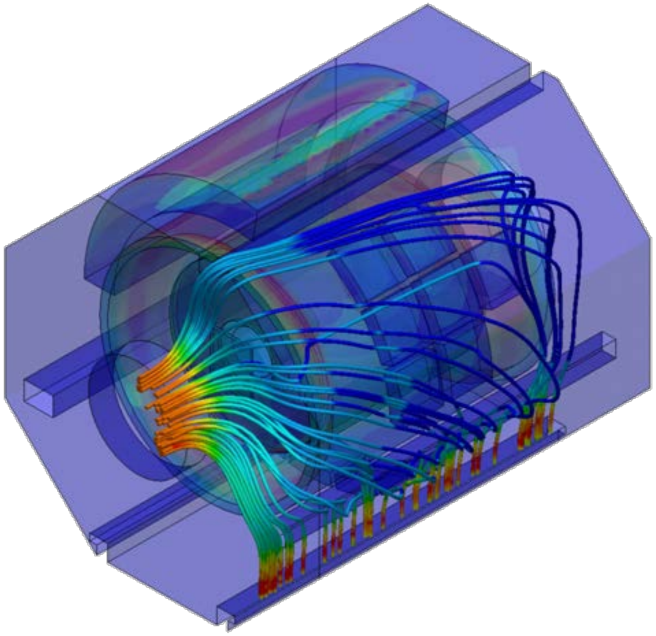
Contents

a) CFD Team activities

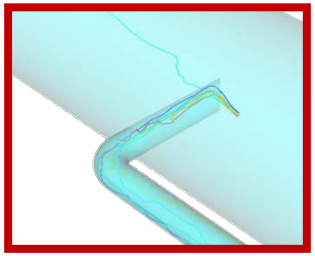
b) Project example: thermo-hydraulic optimization of GTK silicon microchannel heat exchanger for NA62

CERN CFD Team

- The CFD Team provides flow and thermal analyses using Computational Fluid Dynamics (CFD) tools for prototyping, design and development of LHC machine and detectors.
- The main engineering fields covered are:
  - -) cooling of detector components.
  - -) ventilation.
  - -) operational safety.
- CFD tools available: ANSYS (Fluent) and OpenFOAM.
- Computational resources: CERN batch computing service, 320 CPUs.

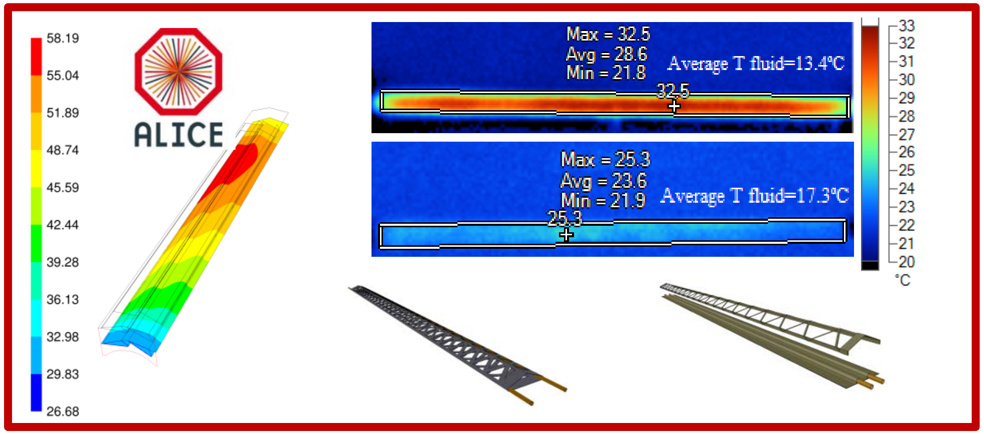


Radioactive aerosol monitoring



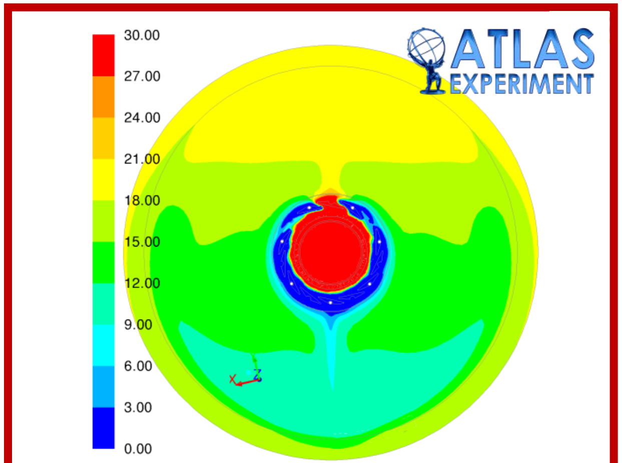
- Guidelines provided for the design of radioactive aerosol sampling at CERN.
- Accurate analysis of ISOLDE case.
- Support to DGS-SEE.

Cooling of ITS-upgrade detector



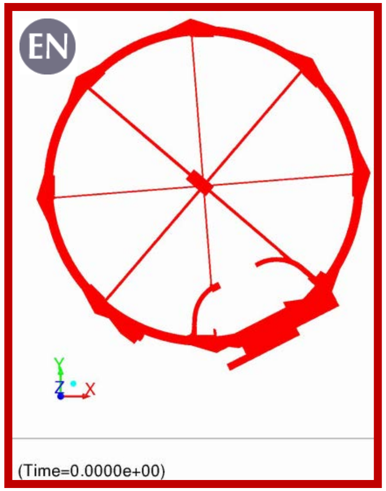
- Several options minimizing mat. budget studied, including air-cooling and ultra-light staves.
- Water and C_4F_{10} experimental cooling tests over the first set of prototypes completed.
- Support to ALICE.

CO_2 cooling of IBL detector



- Assessment of the thermal behavior during nominal operation and bake-out.
- Support to the optimization of the cooling system.
- Support to ATLAS.

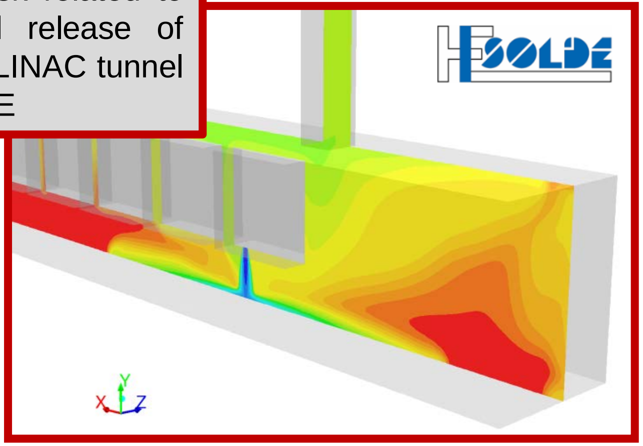
PS Ventilation



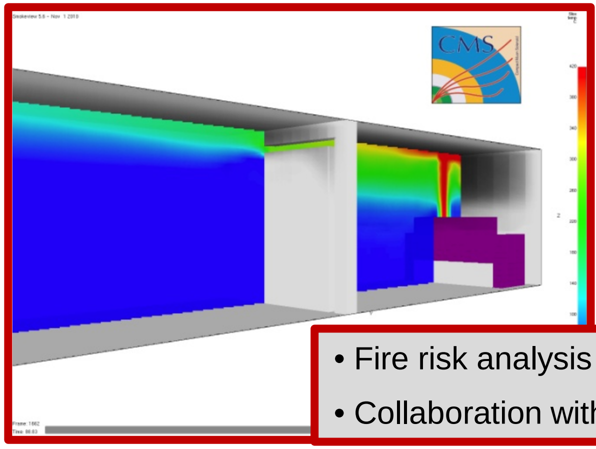
- Assessment of ventilation, activated air flushing and smoke extraction for the update of the PS ventilation system.
- Support to EN/CV.

Accidental Helium Release

Assess the risk related to an accidental release of helium in the LINAC tunnel of HIE-ISOLDE

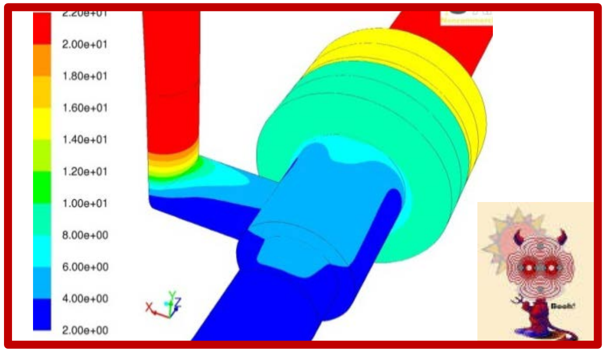


Fire Safety (CMS)



- Fire risk analysis for CMS.
- Collaboration with PH-CMX.

CAST He^3 CFD simulations



- Analysis of the He^3 density distribution in the CERN Axion Solar Telescope.
- Support to CAST.

Thermo-hydraulic optimization of GTK silicon microchannel heat exchanger for NA62

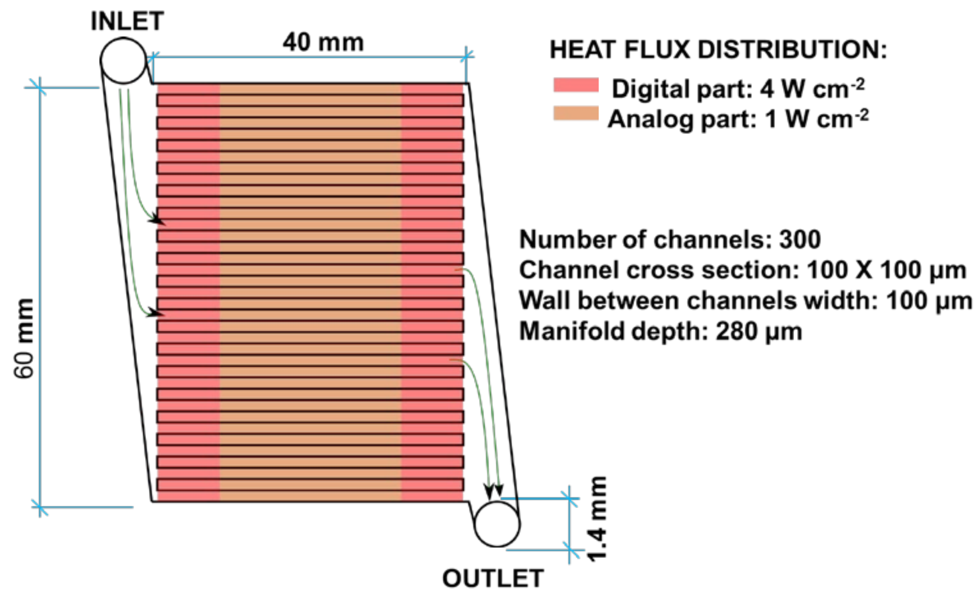
Introduction

- Silicon microchannels is a promising technology in sight of a full integration of the cooling system in future particle physics detectors.
- Silicon displays good thermal conductivity (150 $Wm^{-1}K^{-1}$) but quite low radiation length (~9 cm): in order to achieve a low material budget, thin silicon channel walls are needed, therefore refrigerant pressure drop and mechanical resistance are key design constraints.
- A low material budget heat exchanger is to be designed to cool the GTK sensors of NA62 experiment at -25°C.
- A single-phase cooling system was chosen due to the easier system design and operation as compared to the two-phase (evaporative) option.
- Perfluorohexane C_6F_{14} was chosen, despite its low specific heat, because of its favorable dielectric properties.

Design-0

Design-0 geometry

A first prototype had already been manufactured and tested by CERN PH/DT



Design operating conditions

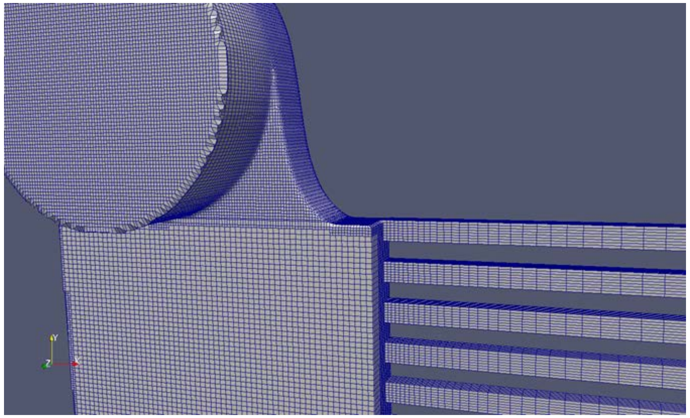
- Refrigerant C_6F_{14}, temperature = -30°C
- Max inlet/outlet temperature rise = 5 K
- Heat load = 48 W
- c_p = 967 J kg^{-1} K^{-1}

Mass flow rate
10 g/s

CFD simulations

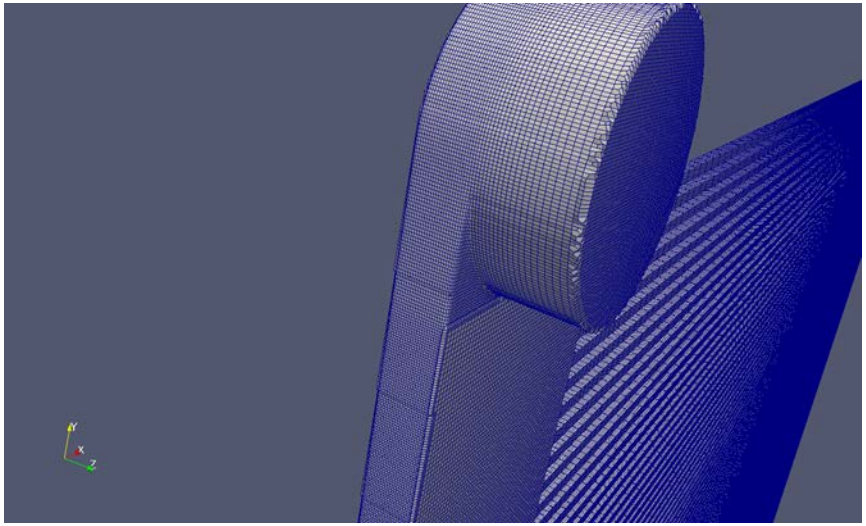
Target

- Restrict the pressure drop to less than 10 bar.
- Optimize the refrigerant flow distribution.
- Minimize the material budget.
- Achieve a uniform temperature distribution on the sensor.

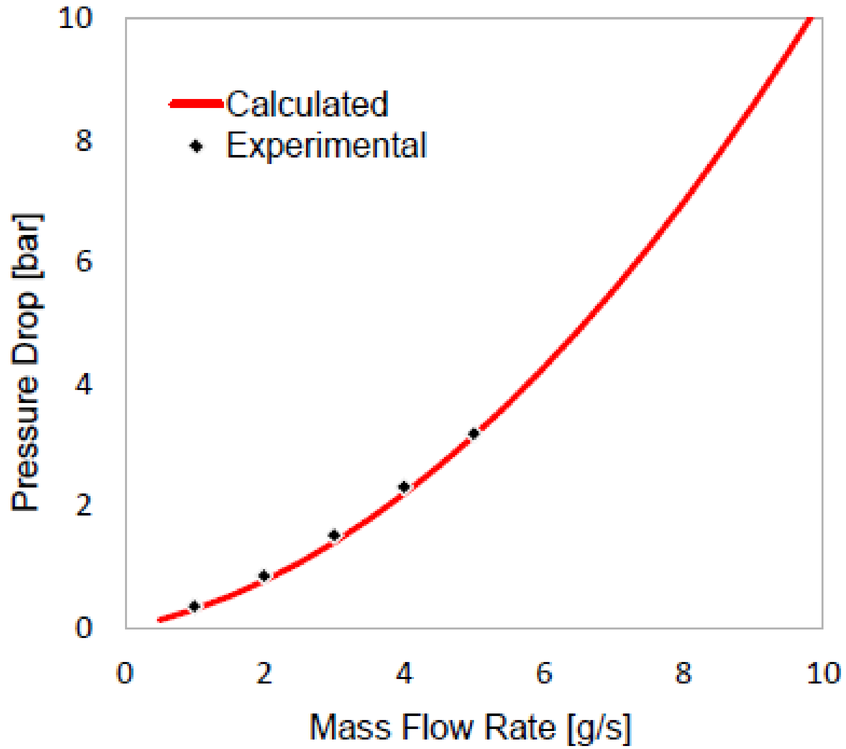


CFD Model

- CFD software: OpenFOAM.
- Mesh: 8 to 22 million cells (depending on geometry and model).
- Applied physics model:
  - 3D, steady-state.
  - Incompressible flow.
  - SST *k*-*ω* turbulence model.



Validation of CFD model



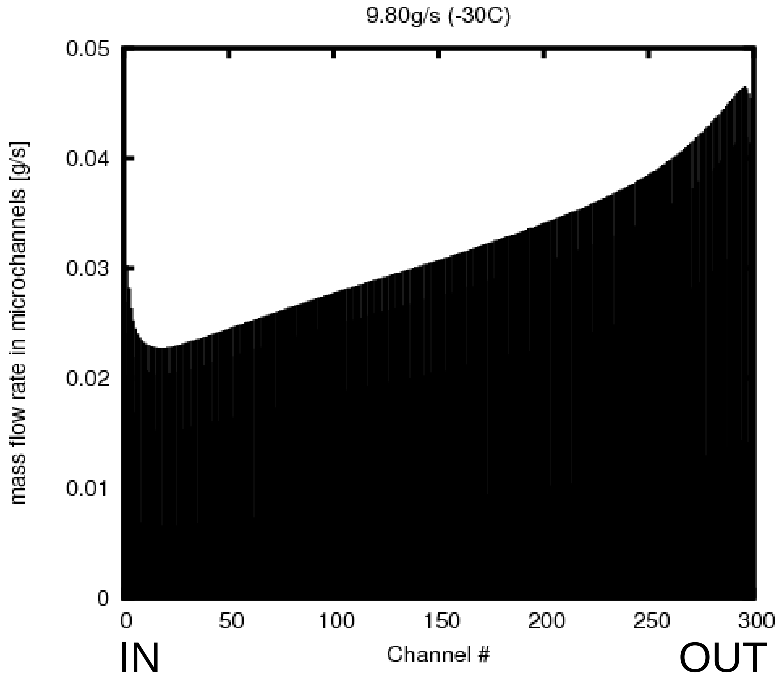
➢ The CFD model was validated against experimental pressure drop data available for Design-0.

Estimated performance of Design-0

Pressure drop

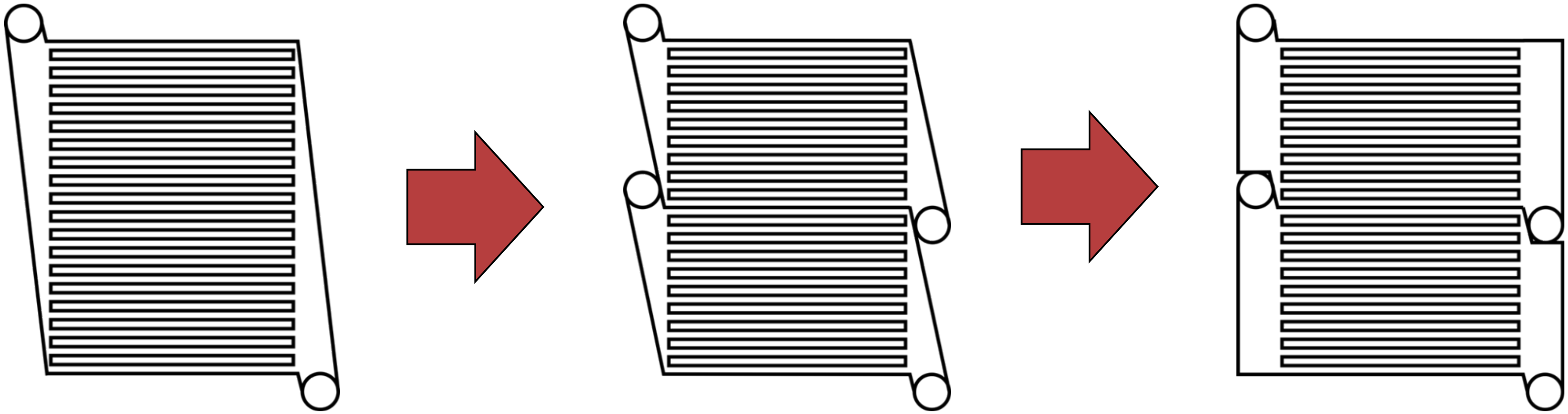
- ❑ The pressure drop predicted by the CFD model at design working conditions is **11.2 bar**
- ❑ This value could give rise to mechanical resistance problems

Flow distribution



- ❑ The Average mass flow rate in each channel is 0.032 g/s
- ❑ The distribution is not optimal
- ❑ The channels close to outlet are fed with almost double the mass flow rate as compared to the ones close to the inlet
- ❑ The temperature rise for the channels close to the inlet is expected to be higher then 5 K

Manifold Optimization



➢ The initial prototype (Design-0) had very high pressure drop, due to the high velocity in the manifolds.

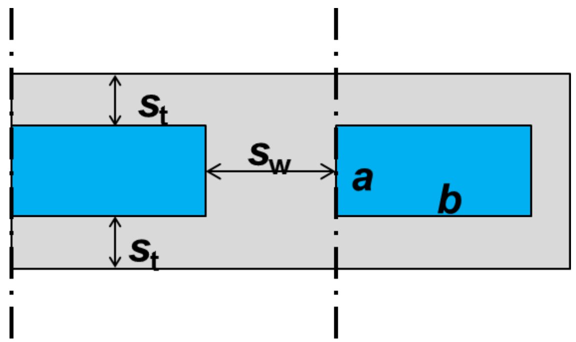
➢ The adoption of double inlets and outlets and rectangular manifolds allows to reduce the operating pressure without affecting the mechanical resistance, thus increasing the reliability and allowing to possibly reduce the silicon wall thickness and material budget.

Influence of manifold design on pressure drop (at fixed microchannels geometry).

Manifold	Pressure drop [bar]
Single triangular (Design-0)	11.2
Double triangular	5.1
Double rectangular	4.3

Channel Optimization

- Once the manifold is optimized, the material budget can be reduced without increasing the pressure drop by adopting rectangular cross section channels.
- In this case, however, mechanical resistance could be affected.



Influence of channel geometry on pressure drop and material budget (in red); analytical estimation, s_t = 25 µm, s_w = 100 µm.

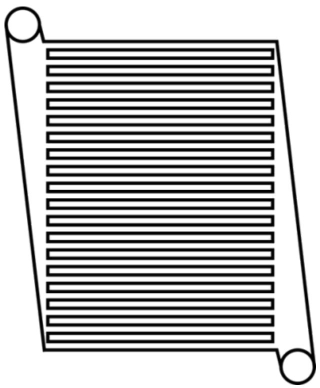
Pressure drop
Material Budget

Aspect Ratio *b/a*	Channel Thickness *a*		
	60 µm	**75 µm**	**100 µm**
1	22.8 bar 0.11 %	11.2 bar 0.12 %	5.3 bar 0.13 %
2	10.7 bar 0.10 %	6.0 bar 0.11 %	3.4 bar 0.12 %
3	8.4 bar 0.10 %	5.0 bar 0.11 %	3.1 bar 0.12 %

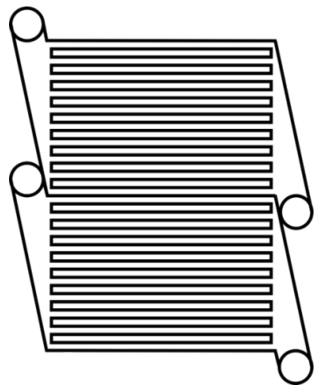
Design-0

x_0 silicon = 0.09 m
x_0 C_6F_{14} = 0.19 m

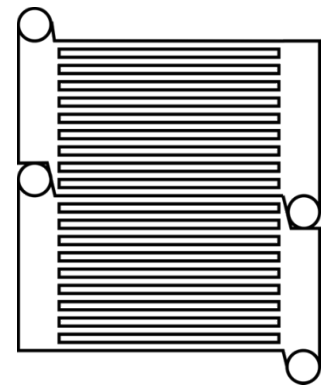
Summary of main optimization steps



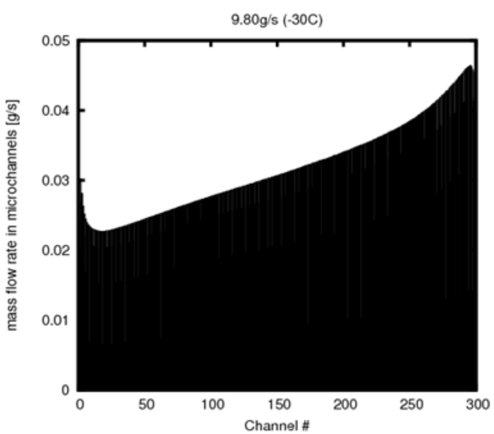
Design-0
Single manifold
Channel 100 X 100 µm



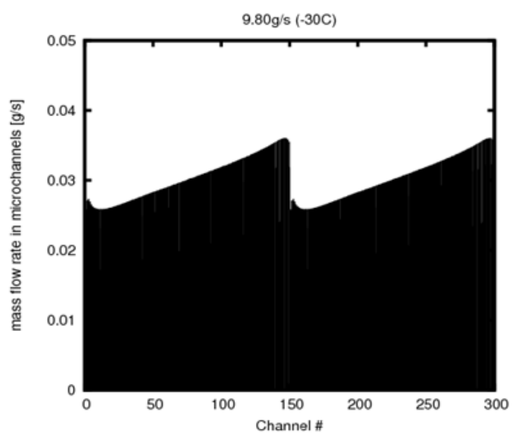
Design-1
Double manifold
Channel 100 X 100 µm



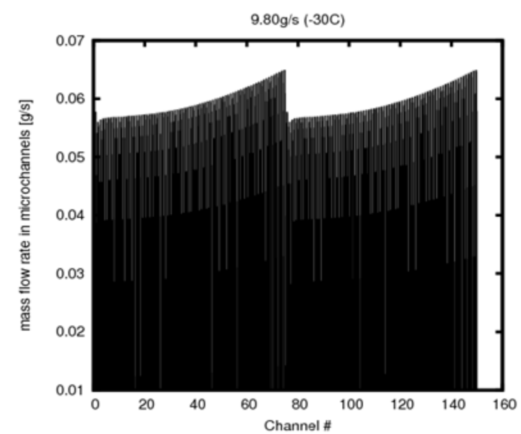
Design-2
Double rectangular manifold
Channel 70 X 200 µm



Δp = 11.2 bar
Material budget = 0.13%



Δp = 5.1 bar
Material budget = 0.13%



Δp = 6.4 bar
Material budget = 0.11%

Thanks for your attention