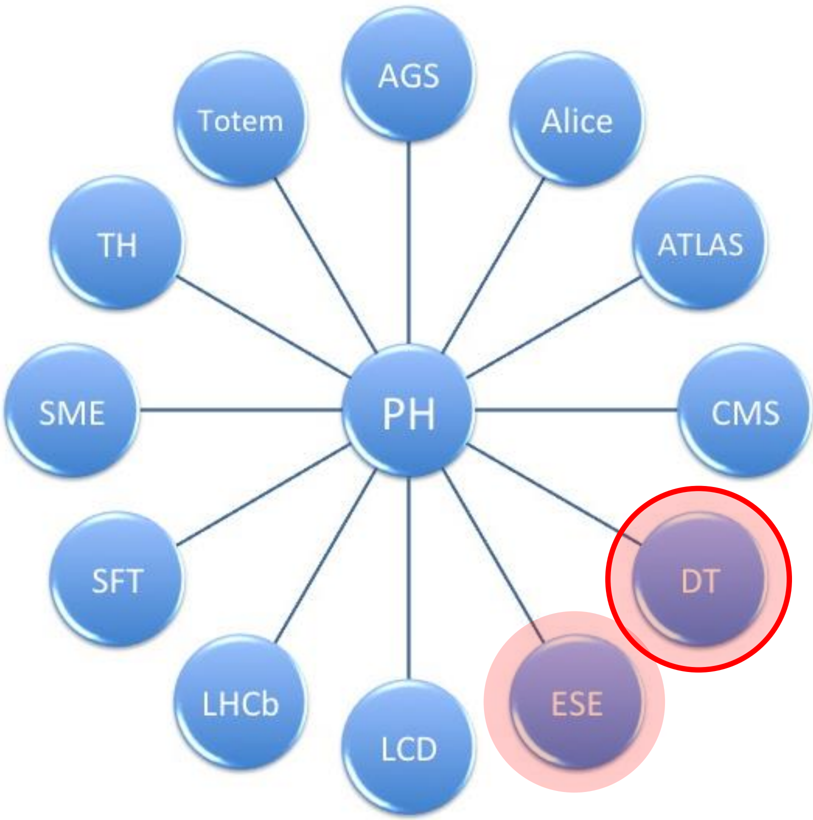
Dessin et intégration de micro-refroidisseurs en silicium

Giulia Romagnoli
on behalf of the CERN PH-DT Group

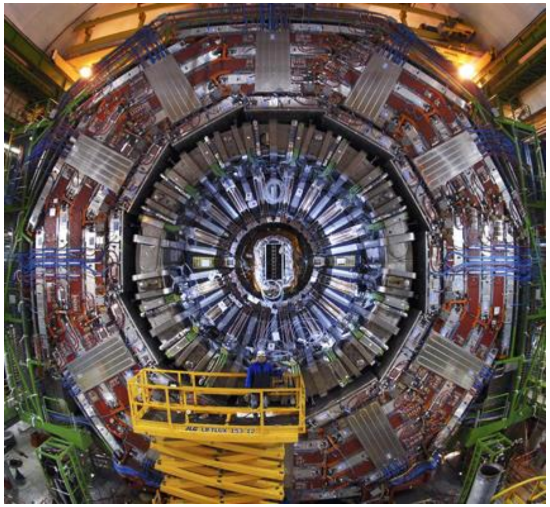


PH-DT
Physics Department – Detector Technologies

The **mandate of the PH-DT** group comprises development, construction, operation and maintenance of particle detectors for the experiments at CERN. The group also offers a range of services and infrastructure for experiments and detector R&D

MicroSystems:

- *microScint* - development of a microfluidic scintillation detector
- *microCool* - implementation of microfabricated on-detector cooling systems
- *microHeII* - study of heat transfer of superfluid HeII in microfluidic networks



MicroSystems engineering

MicroFabrication
Integration of microfabricated devices in detectors
Development of a methodology to estimate the mechanical performance of (silicon) µ-devices

Micro-Channel Cooling at CERN - Concept

For future upgrade plans of LHC and for new experiments under construction, the silicon trackers detectors need:

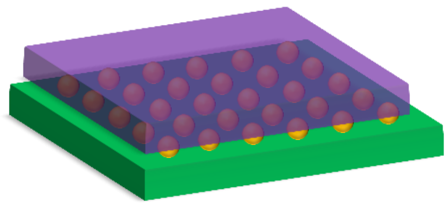
- drastic reduction of inactive material and occupied volume
- highly effective on-detector cooling systems
- precise mechanical integration

PROPOSED SOLUTION

Micro-channels cooling circuits embedded in silicon wafers

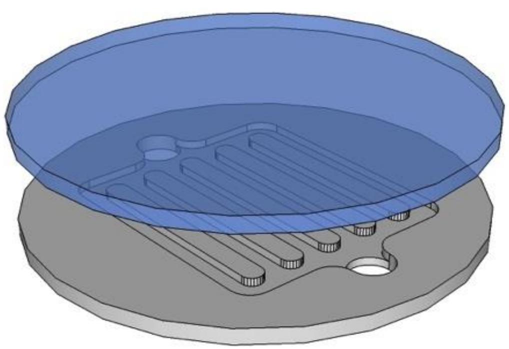
A silicon wafer with etched micro-channels, is bonded to another silicon wafer.
Inside the channels a coolant fluid is circulated in order to remove heat.

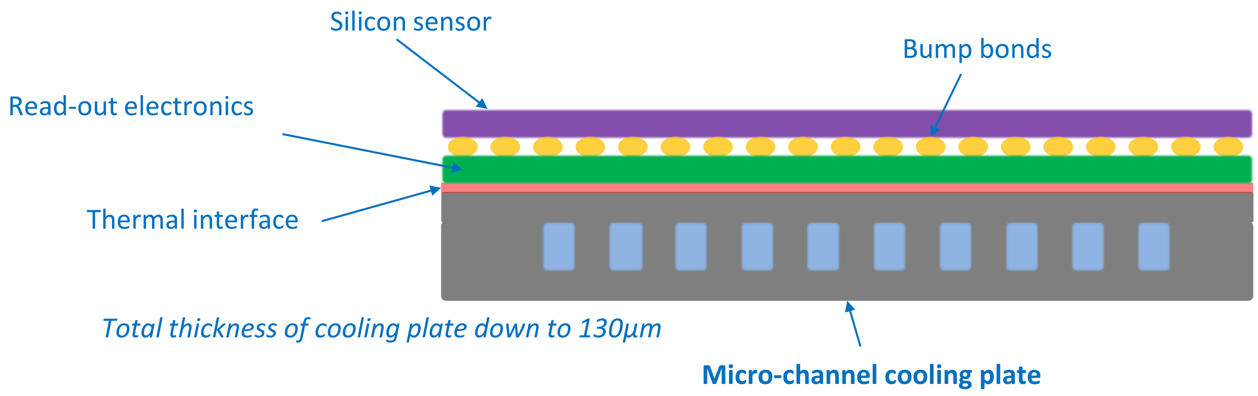
Detector module



+ →

Micro-channel cooling plate

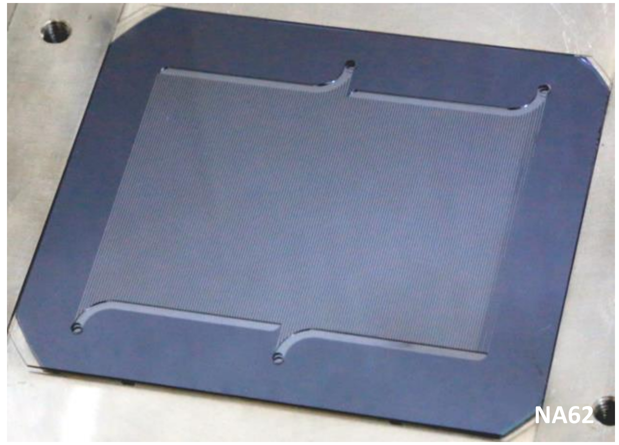




No CTE mismatch!

Micro-Channel Cooling - Motivations

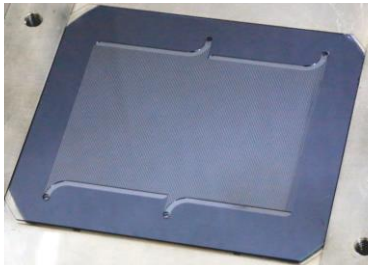
Why?



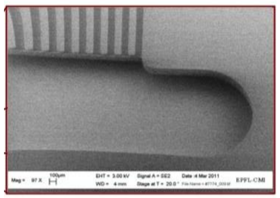
- Cooling is exactly under the heat sources
- Large heat exchange surface (many parallel channels)
- Low mass (just ultra thin silicon layer and thermal interface between cooling channel and substrate)
- Small thermal gradients across the module (no heat flows in the electronics/sensor plane)
- No CTE difference between heat source and heat sink (all material is silicon)

Applications at CERN

NA62 - GTK



- Minimum material in beam area
- -20 °C
- C_6F_{14} single phase
- 2.5 W/cm²
- Total power up to max 144 W

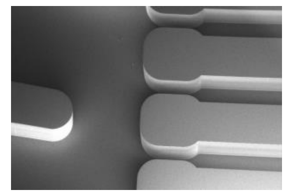


Approved by experiment

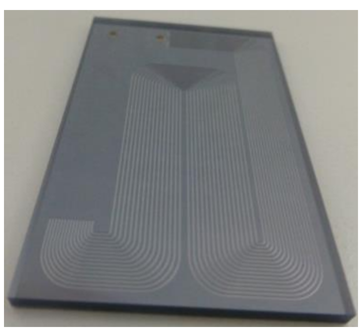
ALICE - ITS

- No material in beam area
- 15 < T < 30 °C
- C_4F_{10} two-phase
- 0.3 W/cm²
- Total power 600 W

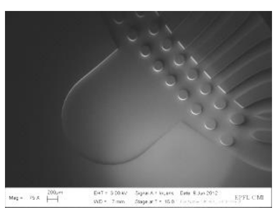
Under study



LHCb – Velo Upgrade



- Reduced material in beam area
- < -20 °C
- CO_2 two-phase
- 1.5 W/cm²
- Total power 1.9 kW

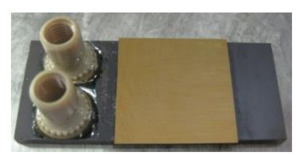


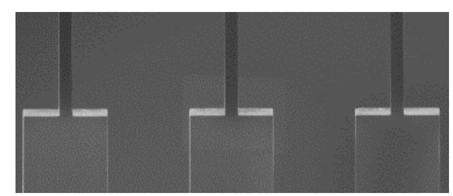
Approved by experiment

ATLAS - Phase II pixel

- Reduced material in beam area
- -15 °C
- CO_2 two-phase
- 0.4 W/cm²
- Total power tbd (~3kW?)

Under study



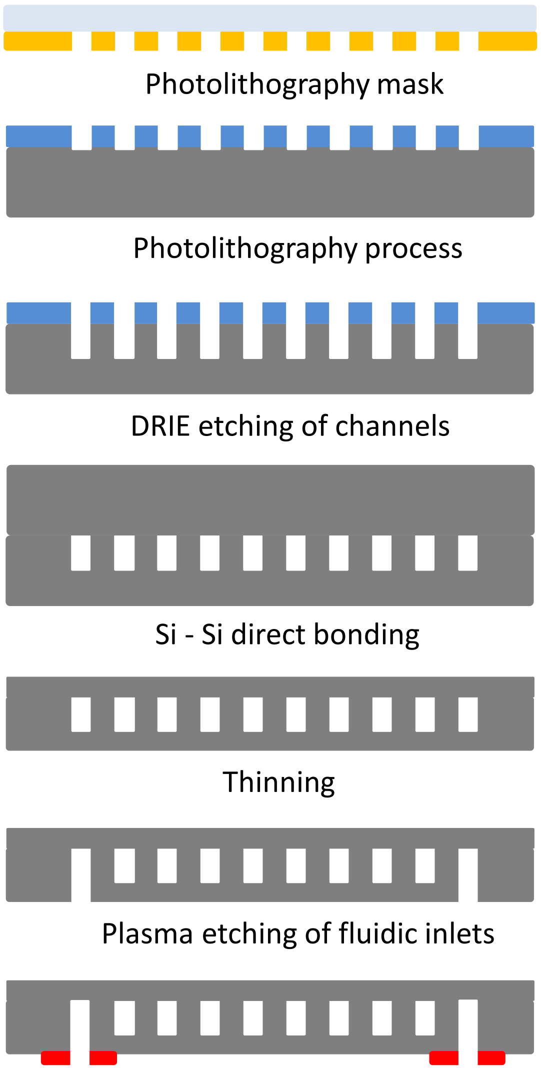


Micro-Fabrication of Cooling Samples

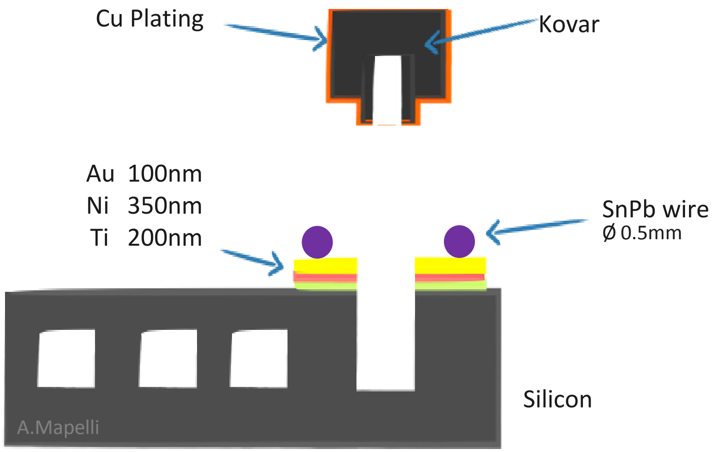
All test devices are produced inside the **CMi** (Center of Micronanotechnology) **EPFL** (Ecole Polytechnique Fédérale de Lausanne) class 100 cleanroom.
Final micro-cooling plates are produced by external micro-fabrication companies.

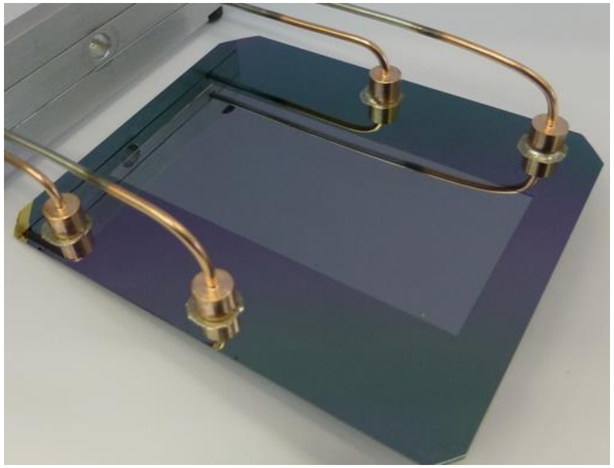
class 100 MEMS cleanroom
4” wafers
(6”wafers)

operation on 50 machines
Photolithography
Etching
Thin Films
Bonding
Thinning
Metrology



Preliminary Fluidic Connectors – Soldering



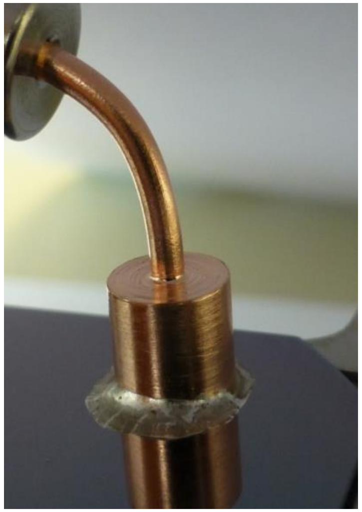


- Kovar connector copper coated
- 3 metal layers deposited on silicon
- SnPb wire or foil inserted around the Kovar connector and on the silicon plate
- Soldering in vacuum at 200°C
- Stainless steel tube laser welded to the connector for the fluid distribution inside the channels.

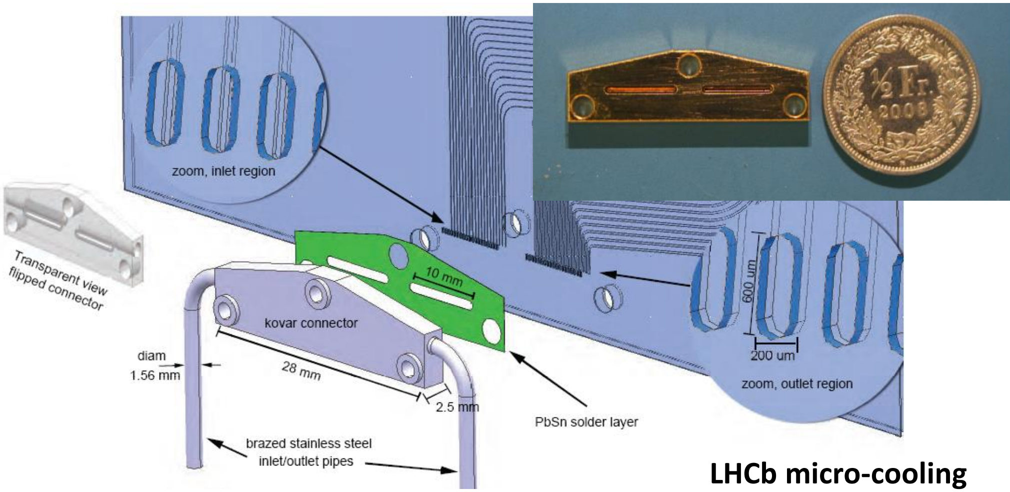
NA62 micro-cooling

Static pressure testing up to 700 bar (pump limit)
Pressure and temperature cycles (0-200 bar / -40 to 40 °C)

Before soldering



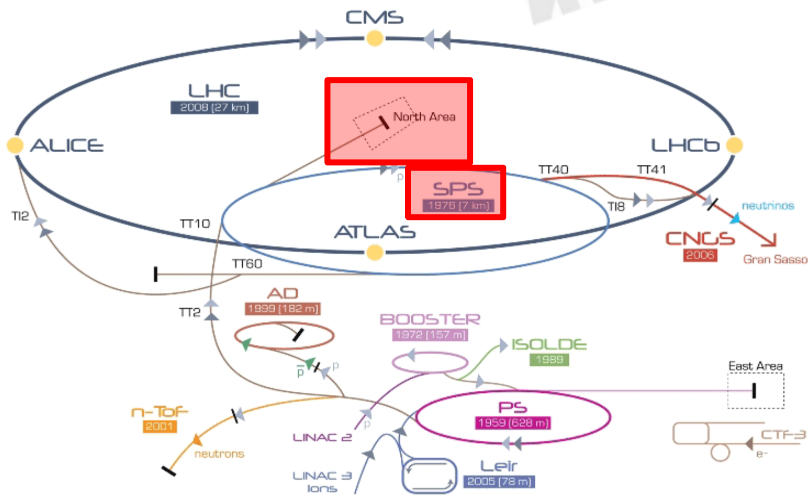
After soldering



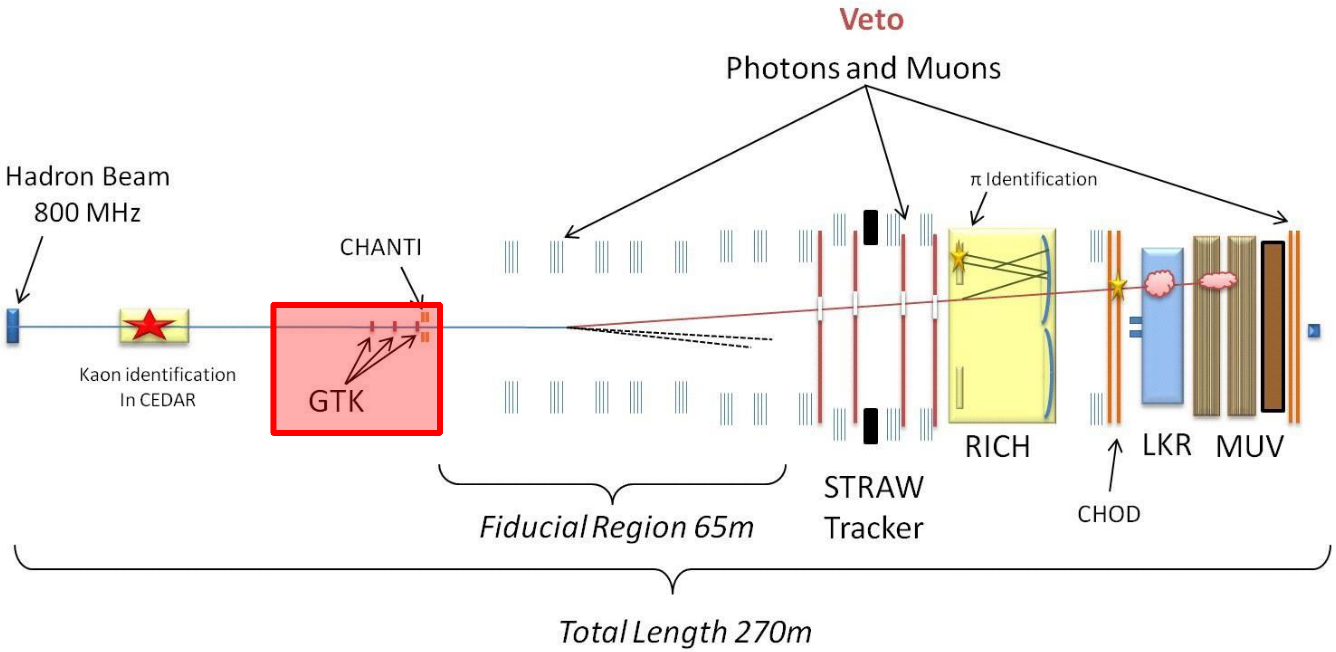
LHCb micro-cooling

NA62 – GTK Detector

The NA62 experiment is a fix target experiment, 270 m long, located in the SPS north area.
The aim is to measure the very rare kaon decay : $K^+ \rightarrow \pi^+ \nu \bar{\nu}$



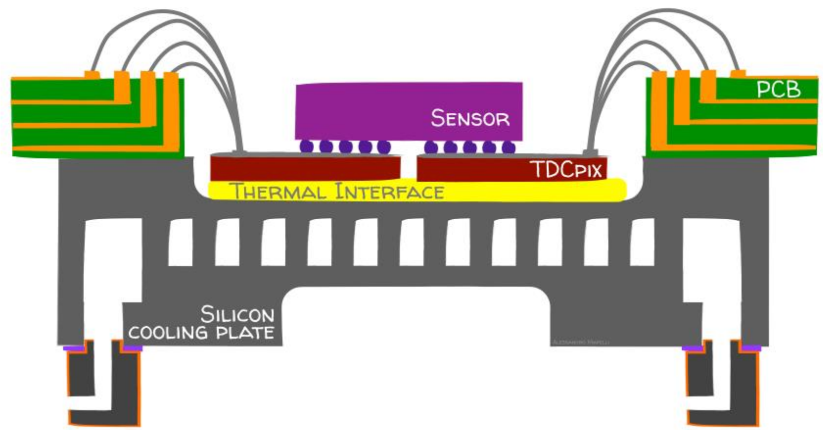
The 3 GigaTracKer stations will provide information on each particle trajectory, momentum and timing within 200 ps.

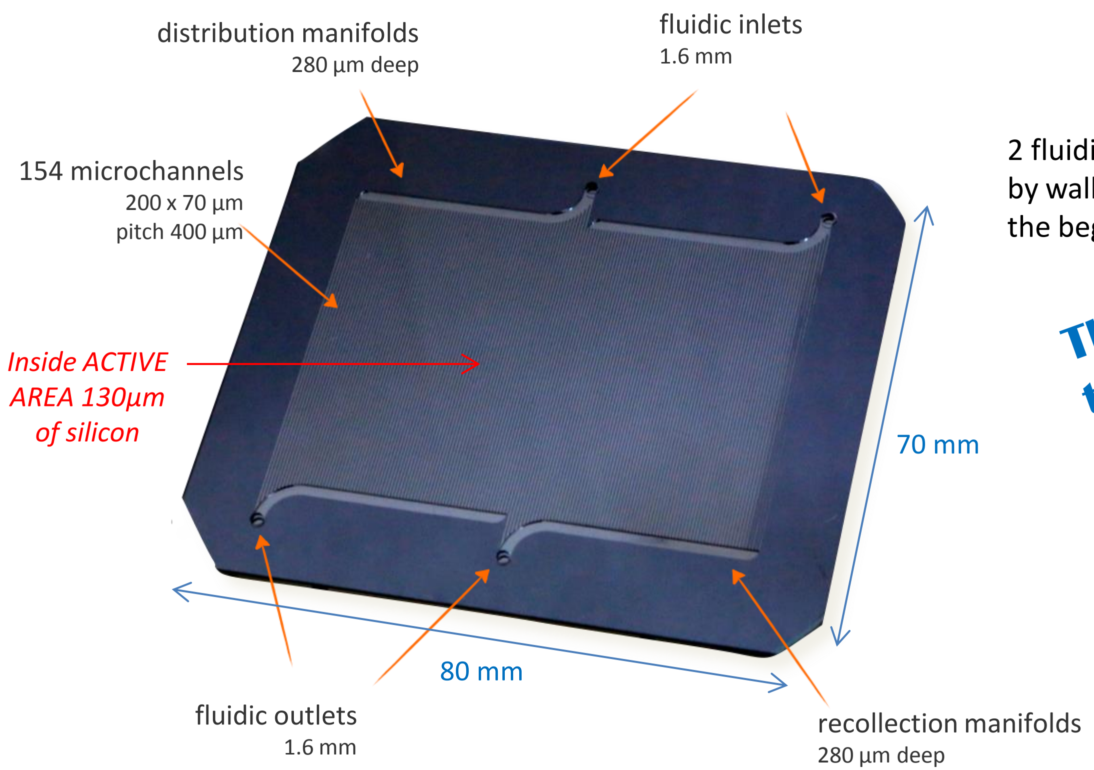


PIONEER EXPERIMENT: Simple geometry and need of mass reduction!!!

NA62 – GTK Detector Micro-Cooling

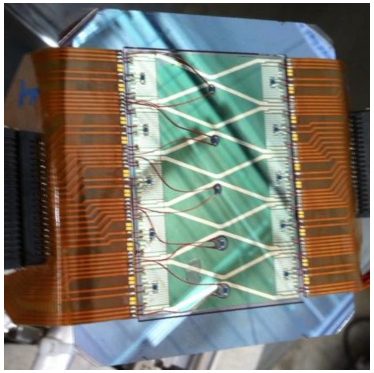
- Minimize the material crossed by particles (thinned to 130µm)
- The target temperature is -20°C
- Heating power density up to 2.5 W/cm^2 on ~60×40 mm^2
- Fluid C_6F_{14} (FC72) in liquid flow
- Maximum ΔT across the sensor 5 °C





2 fluidic circuits: 200 x 70 µm channels , 45 mm long, separated by walls of 200 µm. The fluid is collected in two manifolds one at the beginning and one at the end of the channels.

Thermal testing at CERN



Production of test heaters @ CSEM: silicon chips with metal lines to simulate the chip thermal power.

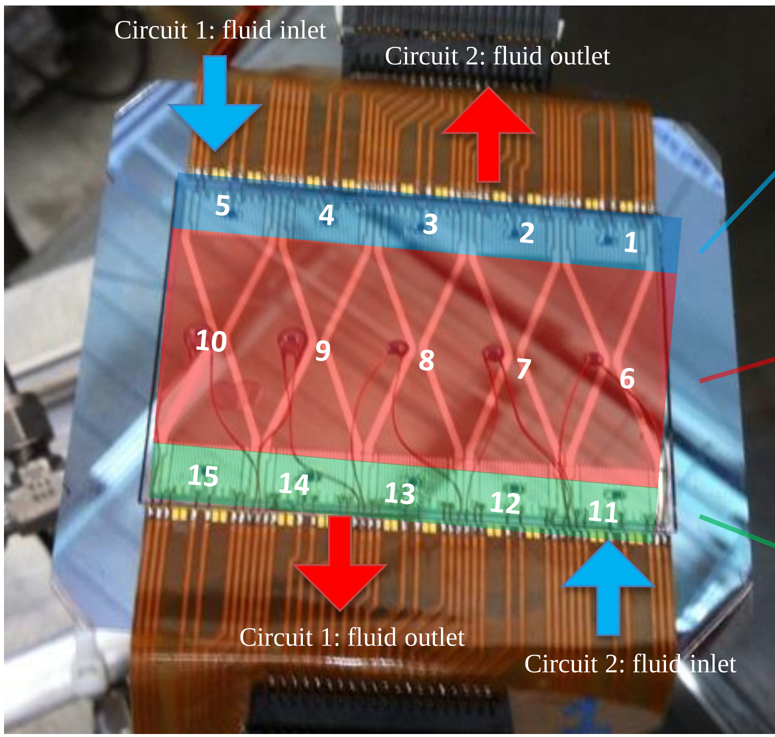
NA62 – GTK Thermal Results

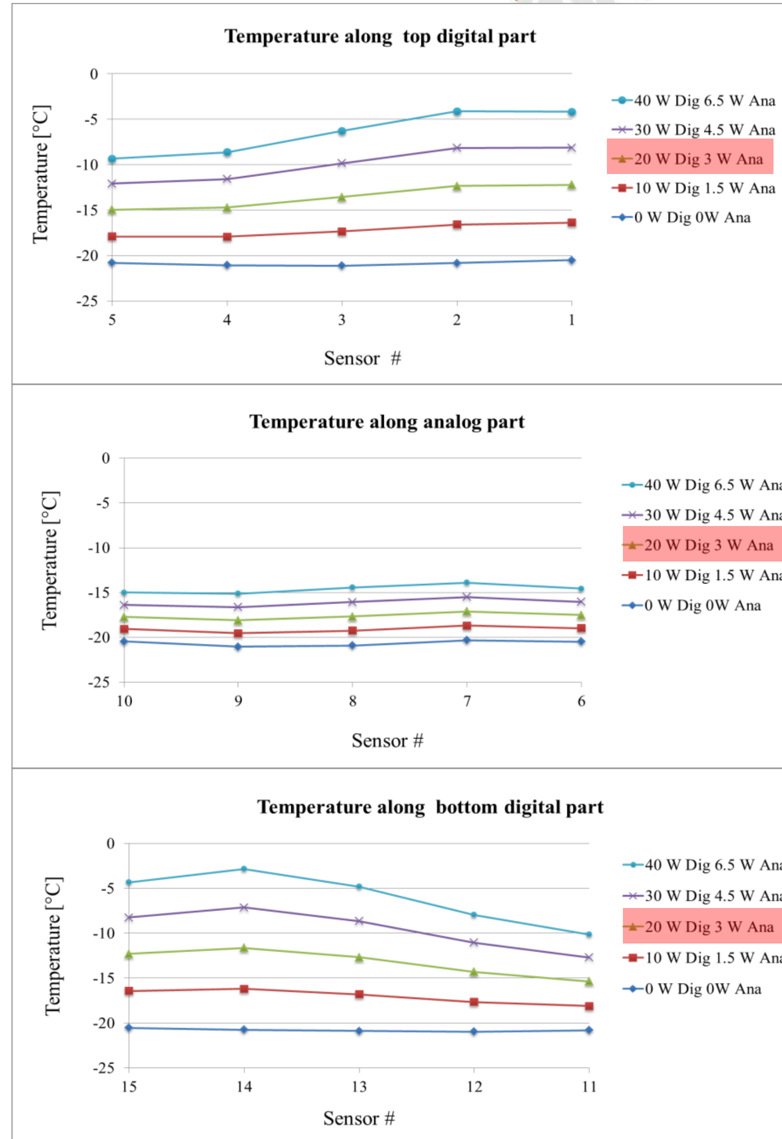
Thermal test

Dummy heaters to simulate the detector power: on analog zone (0.4 W/cm^2) and two digital zones (2.5 W/cm^2). 15 thermocouples to measure the surface temperture, increasing the heating power from 0 to maximum power.

- Inlet temperature: -21°C (will be -25°C in operation)
- Mass flow 8 g/s

COOLING FLUID: perfluorocarbon C_6F_{14} (FC72)



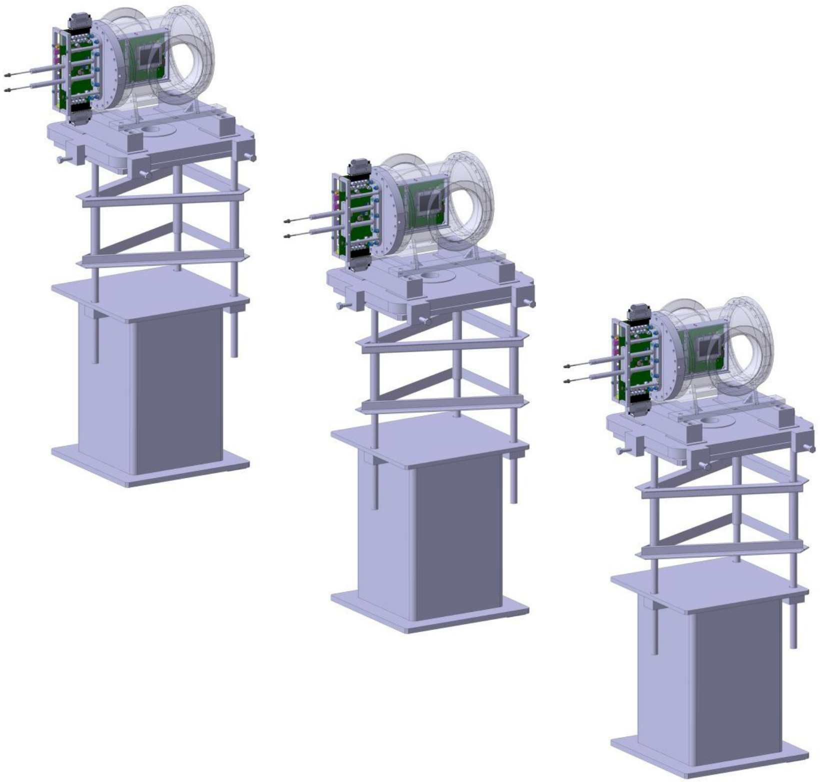


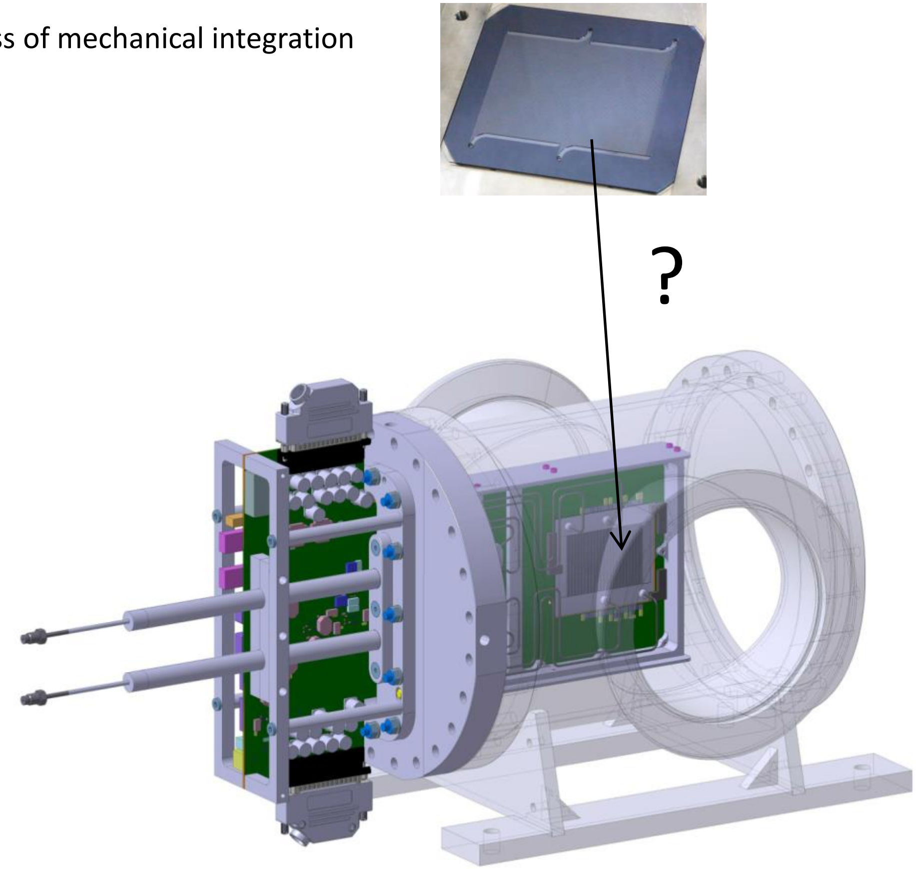
Nominal conditions: max Δt_{sensor}= 1 °C, max Δt_{chip}= 3 °C, max Δt_{module}< 5 °C

NA62 – Mechanical Integration

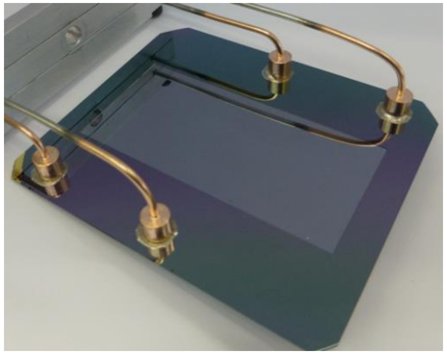
- 3 GTK stations are being assembled to be installed in the SPS in October 2014 for the 1st Physics Test Run.
- The GTK detectors will be the first modules to be thermally managed with a silicon microfluidic on detector cooling system in HEP.
- The modules will be replaced every year until 2018.

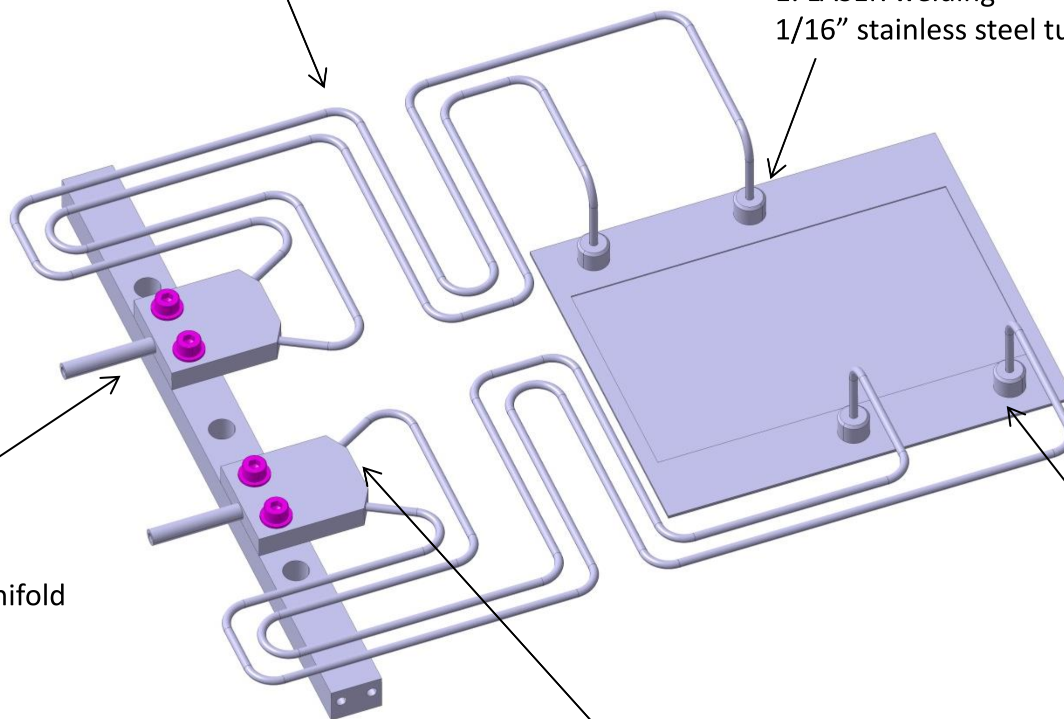
Each GTK station is assembled with a standard and repeatable process of mechanical integration using mechanical precision jigs and mechanical mock-ups.





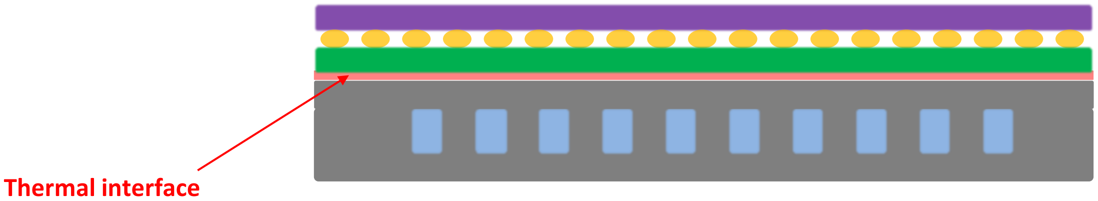
Soldering and Bending



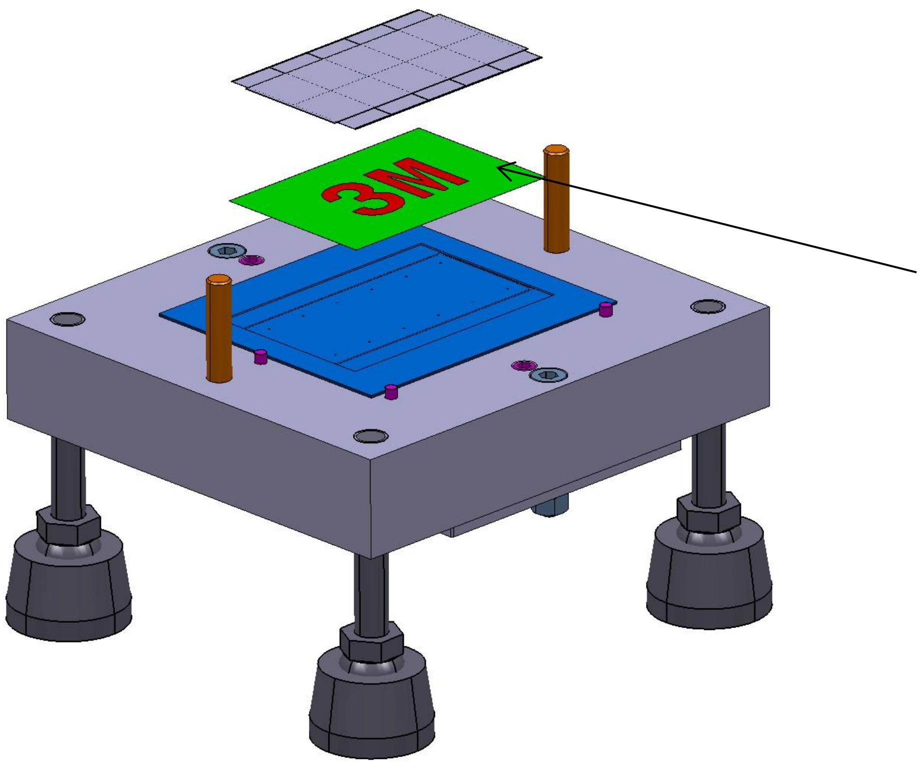


Procedure developed in collaboration with CERN-EN-MME

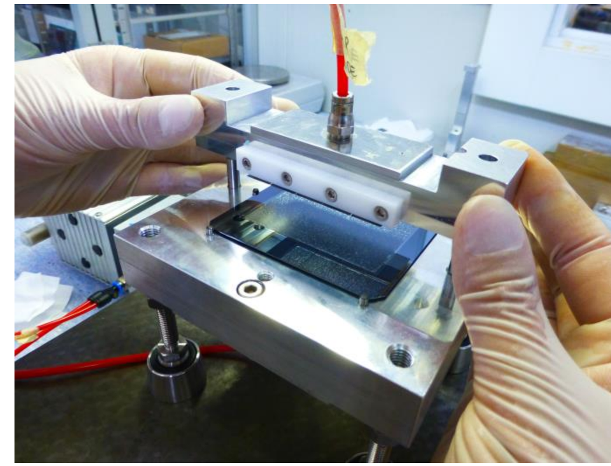
Gluing Detector on Cooling Plate

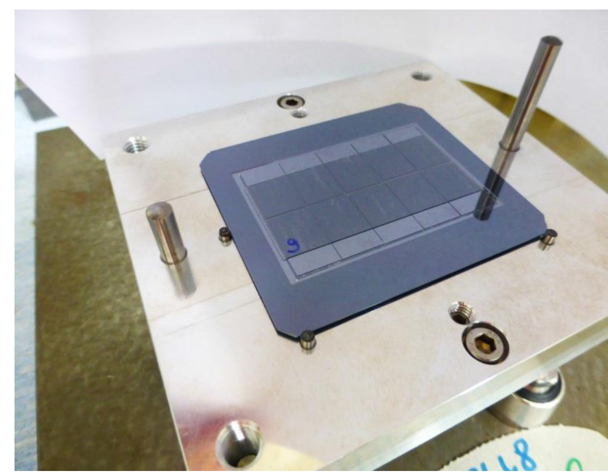


Gluing the detector assembly on the cooling plate
(good thermal contact, precise alignment, no air bubbles, …)



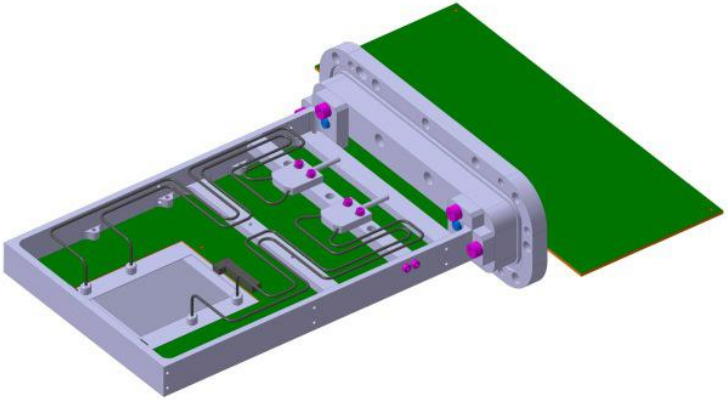
TAPE 3M - 9461P
(double side tape 30 µm thick)

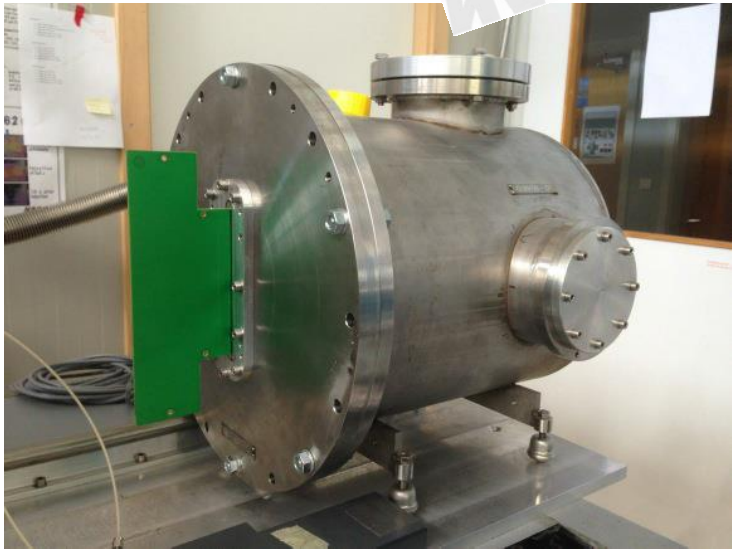




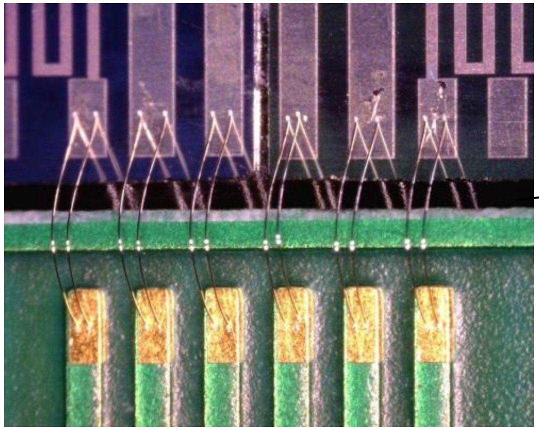
Cooling Device to PCB

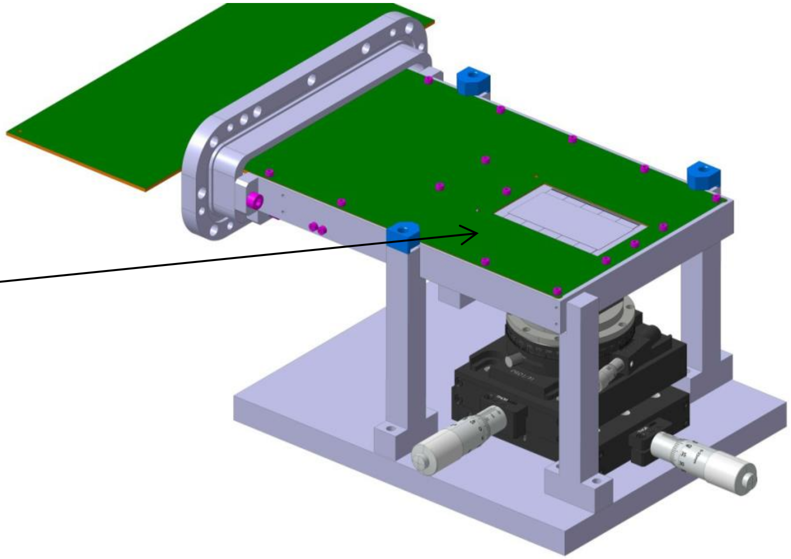
Gluing of vacuum flange to the read-out board to guarantee leak tightness.





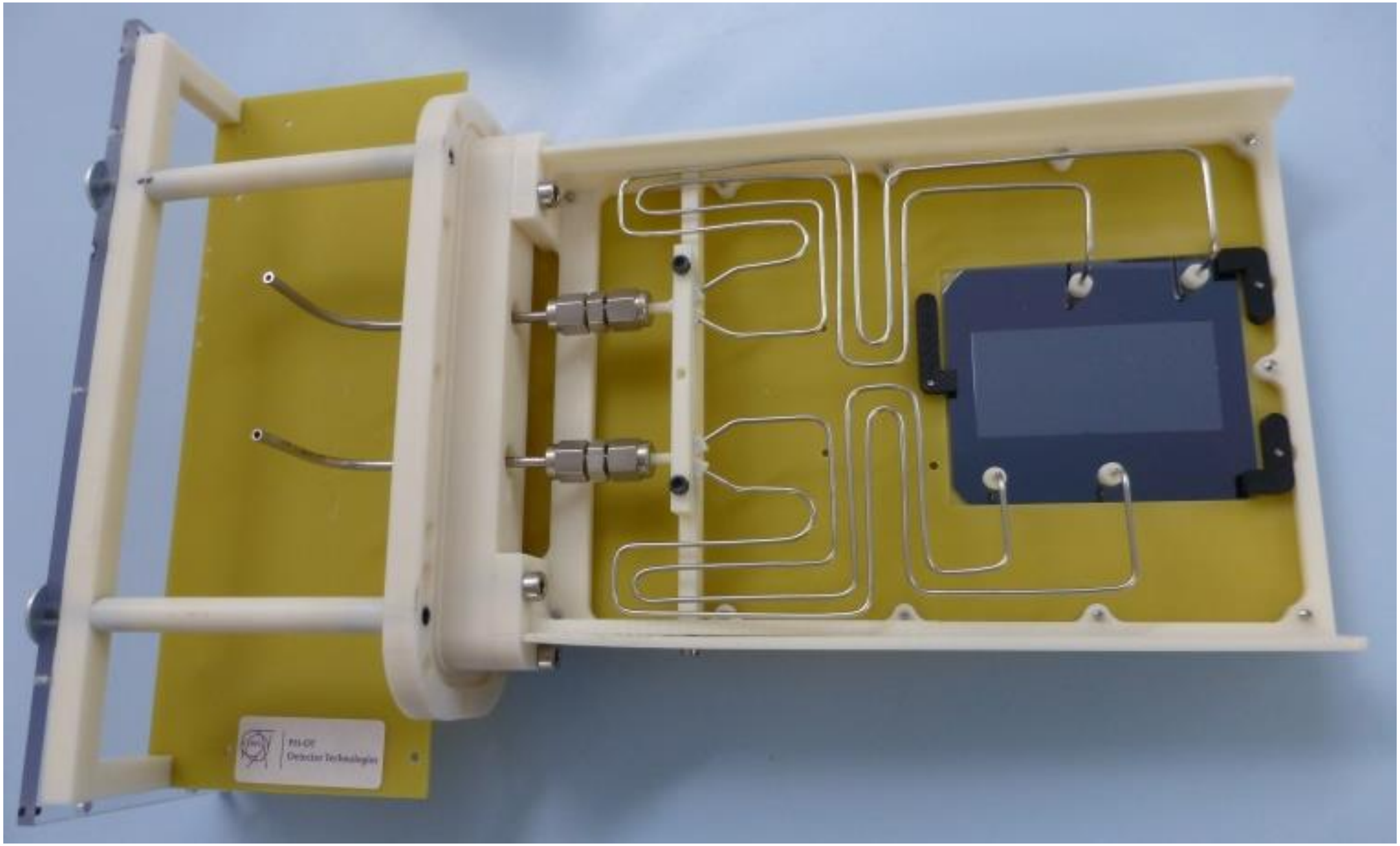
Supporting and aligning during wire-bonding process
(18000 wire bonds with a pitch of 73 µm wire-bonding)





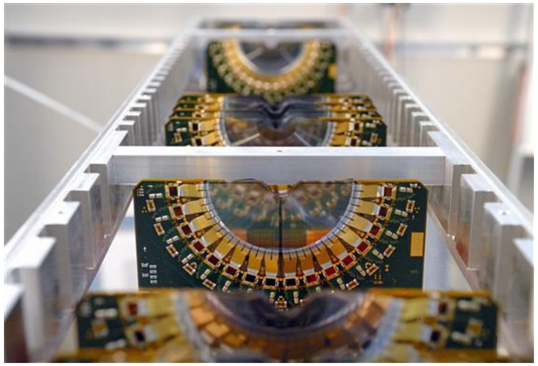
First Mechanical Maquette

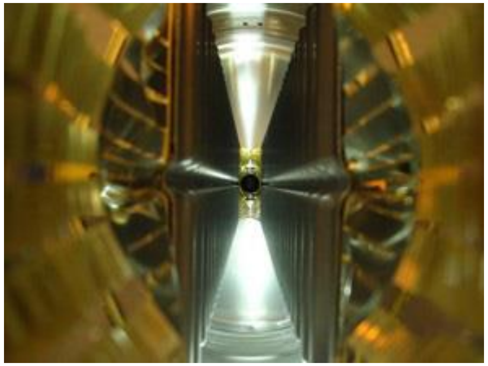
Most components were 3D printed to validate their design before machining



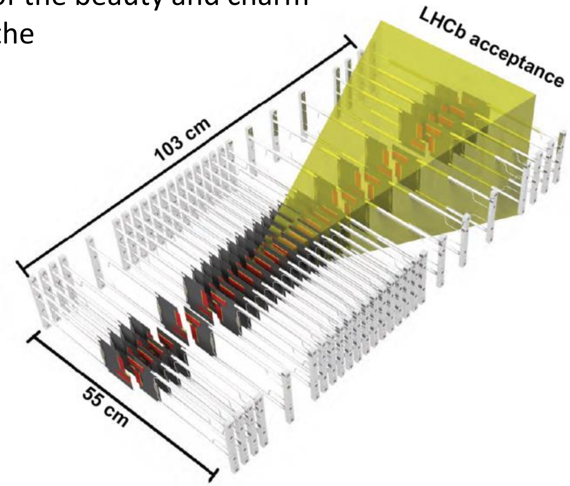
Alessandro Mapelli, Paolo Petagna, Jordan Degrange, Jerome Noel, Bernard Brunel, Michel Morel

LHCb – VELO Detector Upgrade

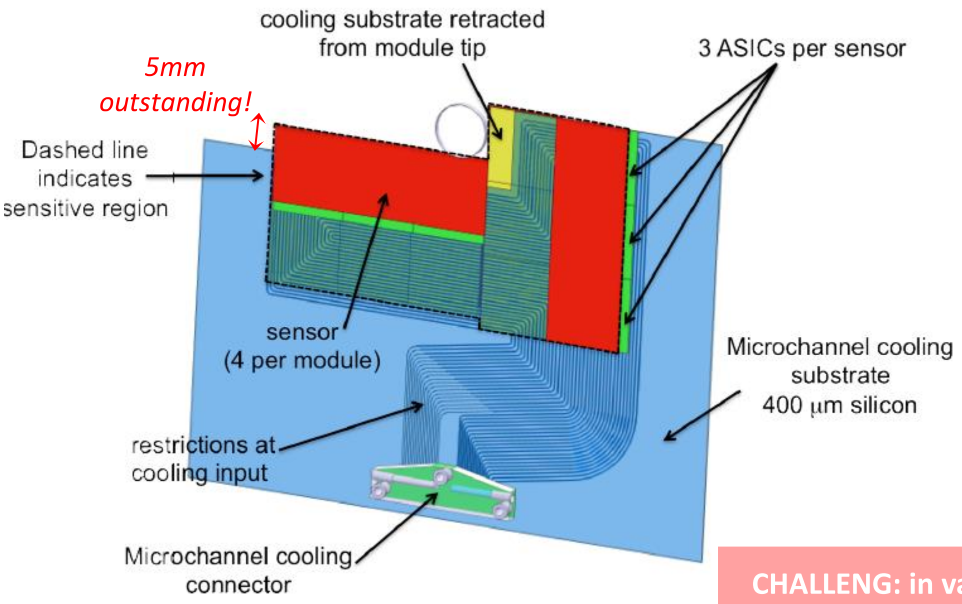




The Vertex Locator (VELO) is the inner tracking system of the LHCb experiment; its excellent spatial resolution makes it possible to identify the secondary vertices from decays of the beauty and charm hadrons produced in the LHC beams collisions.

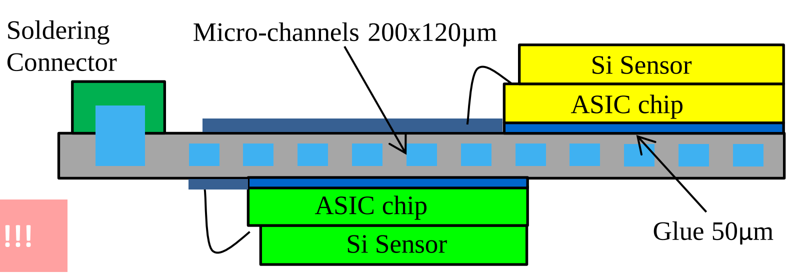


Micro-channels with evaporative CO_2



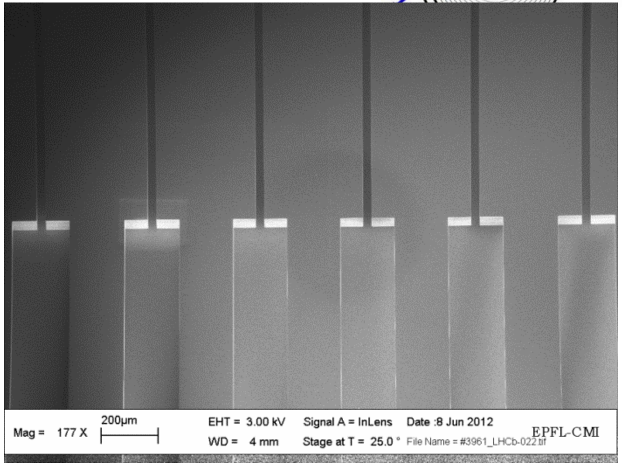
CHALLENG: in vacuum!!!

VELO 2018 upgrade:
- high radiation environment (~5 10^15 neq/cm^2)
- silicon sensor temperatures < -20°C
- hybrid pixel detector power densities ~ 1.5 W/cm^2
- 2 rows of 26 modules each



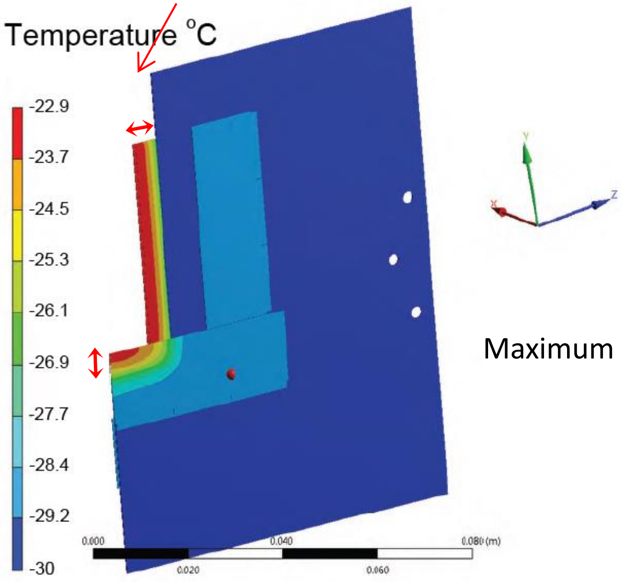
LHCb – VELO Thermal Simulations

Each channel starts with a narrow part (60x60 µm^2, 400 µm pitch) where the CO_2 enters as a sub-cooled liquid. The length of the narrow portion is dimensioned to induce a desired pressure drop and bring the CO_2 flow close to saturation conditions at its end. The sudden increase of the channels width at the entrance of the wider channels causes the liquid to start evaporating due to the expansion



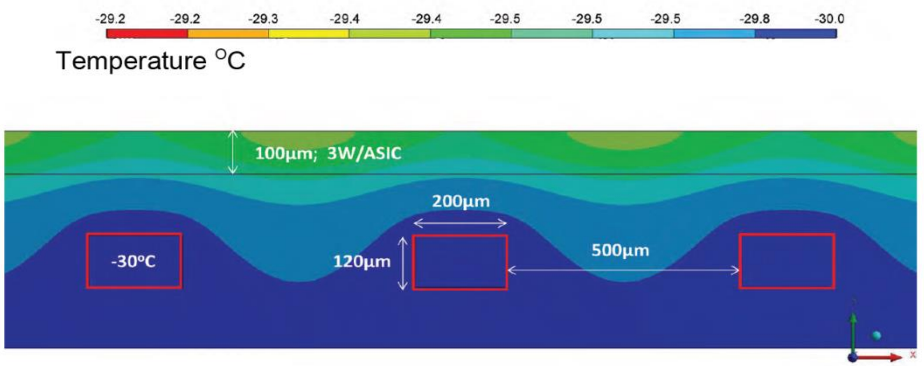
Finite element analysis: 400 µm thick silicon substrate with 200x120 µm^2 micro-channels, -30°C fixed temperature boundary, 100 µm thick heat source (1.5 W/cm^2)

Cooling system retracted from detector tip!



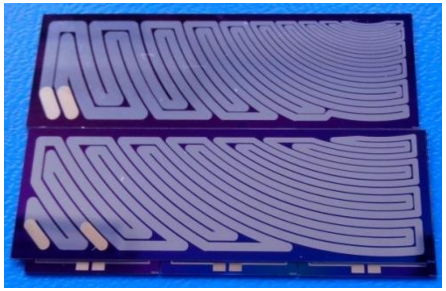
Maximum ΔT = ~ 7°C

-30°C boundary condition used for FEA in solid silicon



Optimal separation of 500 µm between channel. Negligible ΔT between the coolant and heated surface. Maximal bonding surface.

LHCb – VELO Thermal Results



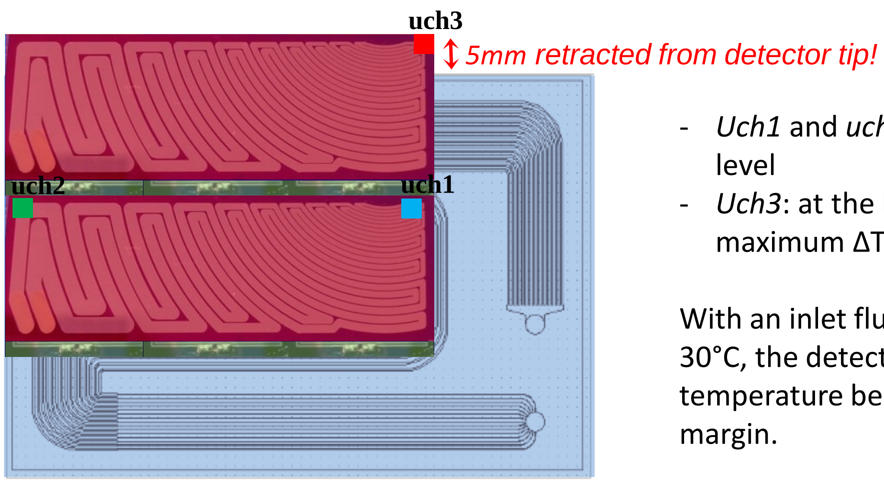
Silicon sensor heater

ASICS chips heaters

40x60 mm^2 Pyrex-silicon sample with simpler micro-channels pattern

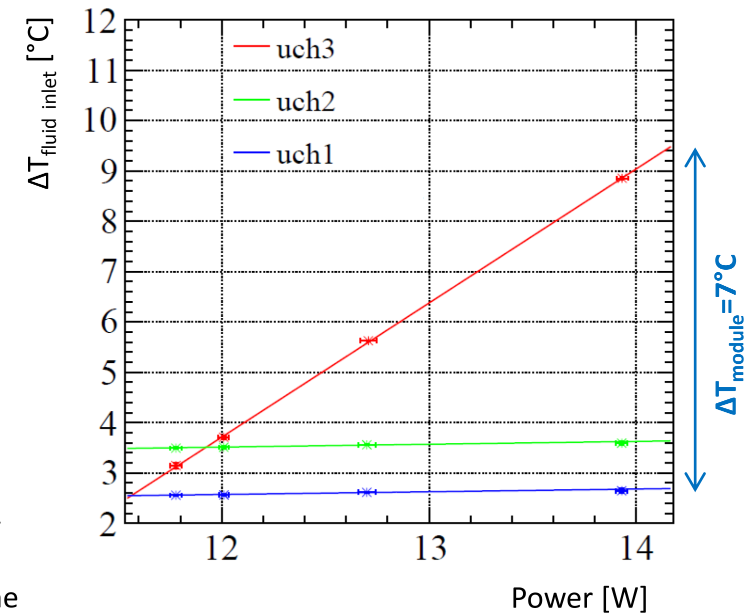
First thermal tests performed gluing detector dummy heaters on a Pyrex-silicon sample (next prototypes foreseen in Si-Si).

- Test under vacuum 10^{-5} mbar
- CO_2 inlet temperature -30°C
- 3 temperatures sensors: *uch1*, *uch2* and *uch3*



- *Uch1* and *uch2:* almost constant level
- *Uch3*: at the highest power the maximum ΔT is of 7°C

With an inlet fluid temperature of -30°C, the detector can be held at a temperature below -20°C with some margin.

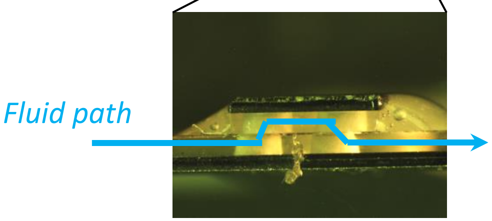


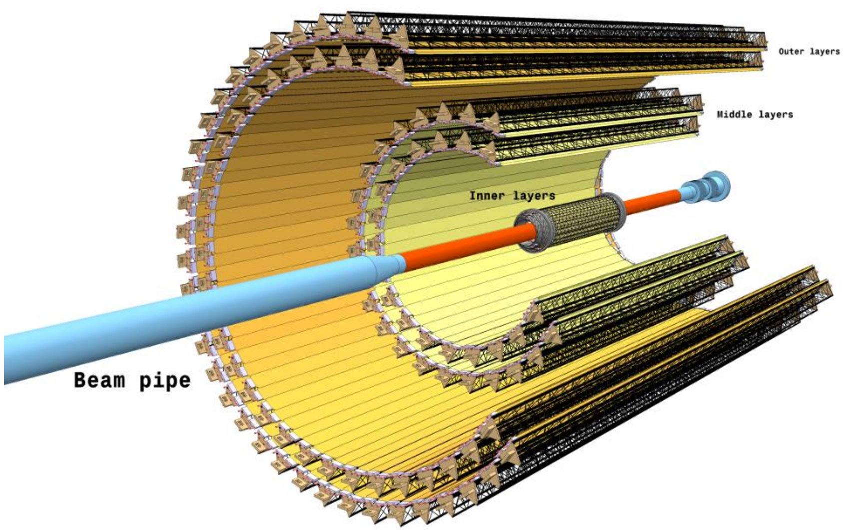
Jan Buytaert, Raphael Dumps, Oscar A. De Aguiar Francisco

ALICE ITS – Towards a Microfluidic Stave

Baseline solution for mechanics and cooling developed from C. Gargiulo *et al.*

First prototype of microcooling stave 270 mm long.





Andrea Francescon

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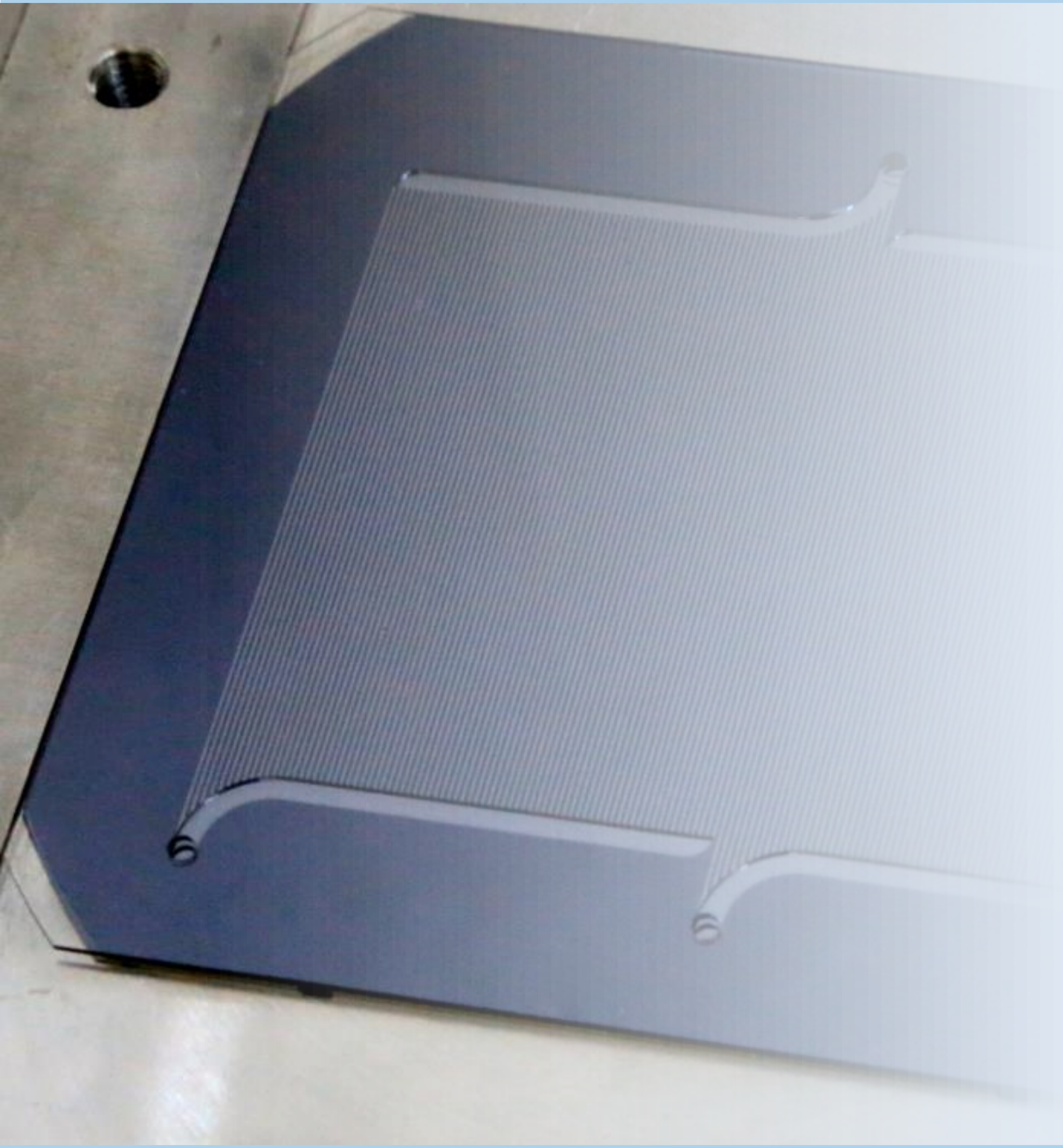

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