MICROCHANNEL COOLING FOR SILICON DETECTORS

Status and perspectives at AIDA-2020 mid-term

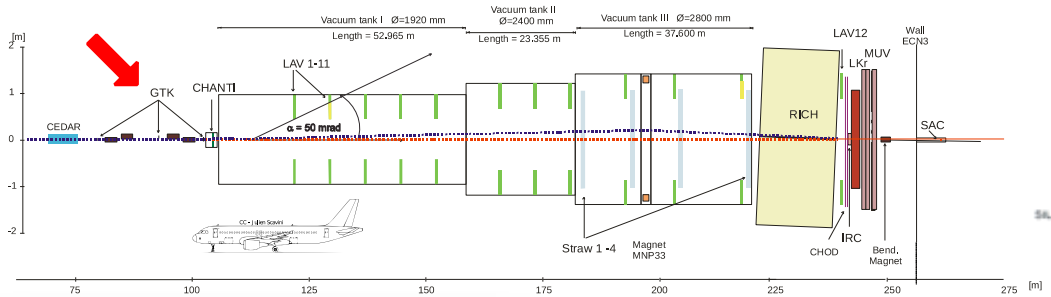
Alessandro Mapelli
Paolo Petagna

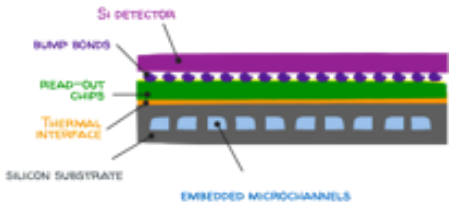
22 February 2017

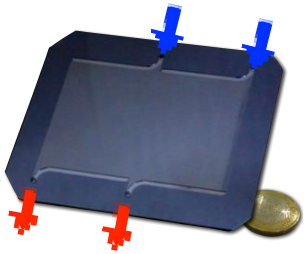
EP-DT
Detector Technologies

NA62-GTK – SILICON MICROCHANNEL COOLING

NA62 is the first experiment to use silicon microcooling plates for the thermal management of their GTK pixel detectors (since 2014).



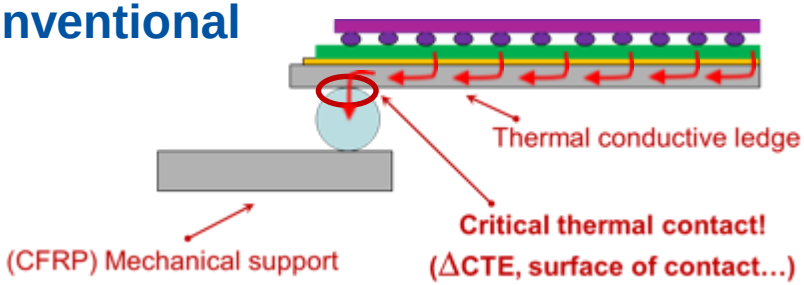
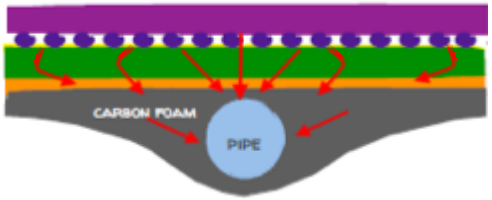
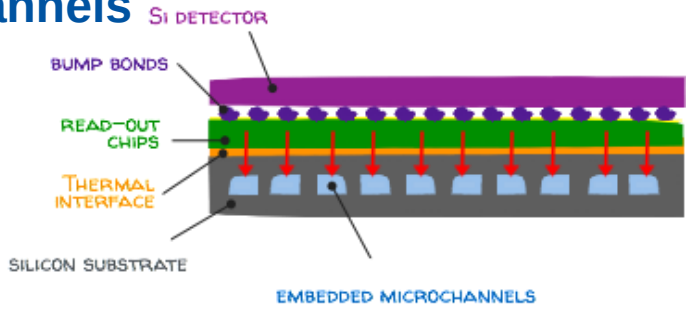




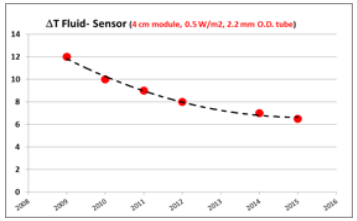
- 3 detector modules
- Liquid C_6F_{14}
- T_{op} below -10ºC
- Power dissipation 25W-48W over 6x4cm^2

A. Mapelli *et al.* 2012 JINST 7 C01111
P. Petagna *et al.*, Microelec. Journal 44 (2013) 612–618
G. Romagnoli *et al.*, Microelec. Eng. 145 (2015) 133-137

THERMAL FIGURE OF MERIT

approach	TFM
conventional 	20
integrated 	12
microchannels 	5-8 *liquid*
	3 *bi-phase*

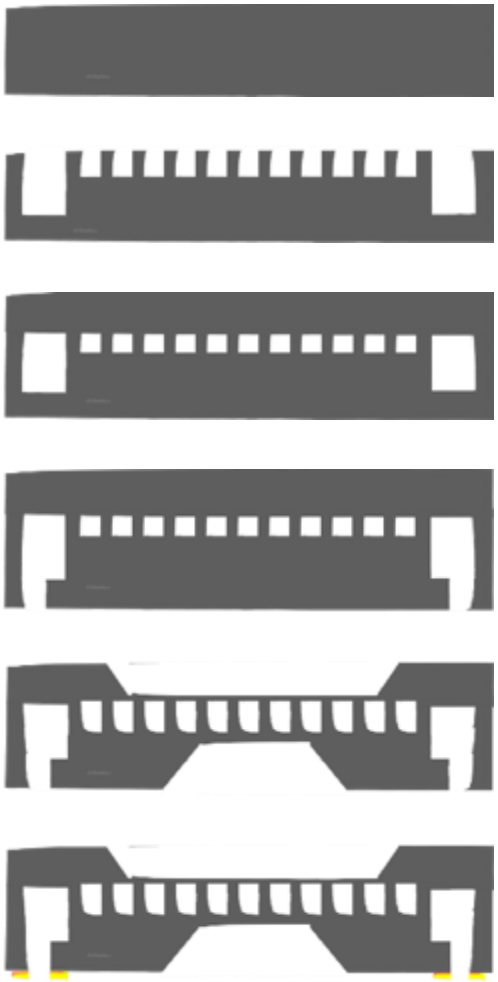
$$TFM = \frac{(\Delta T\ fluid\text{-}sensor)}{(power\ density)}$$



NA62-GTK, C_6F_{14}

LHCb VeLo, CO_2

NA62-GTK – MICROFABRICATION OF COOLING PLATES



8” Si wafer

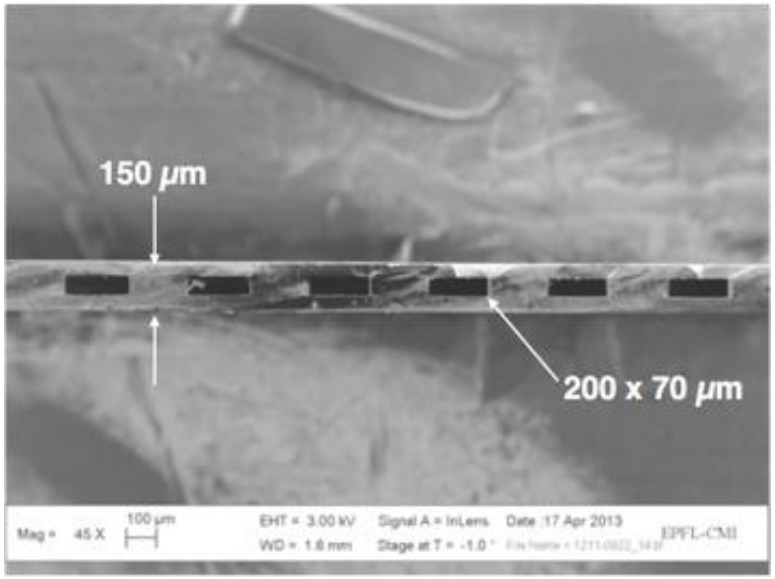
DRIE channels

wafer bonding

DRIE inlets

DRIE acceptance

Metallization



- **Design by CERN EP-DT**
- **Prototypes fabricated by EP-DT at EPFL-CMi on 4” wafers**
- **Pre-production series by IceMOS on 6” wafers**
- **Two batches fabricated at CEA-Leti on 8” wafers**

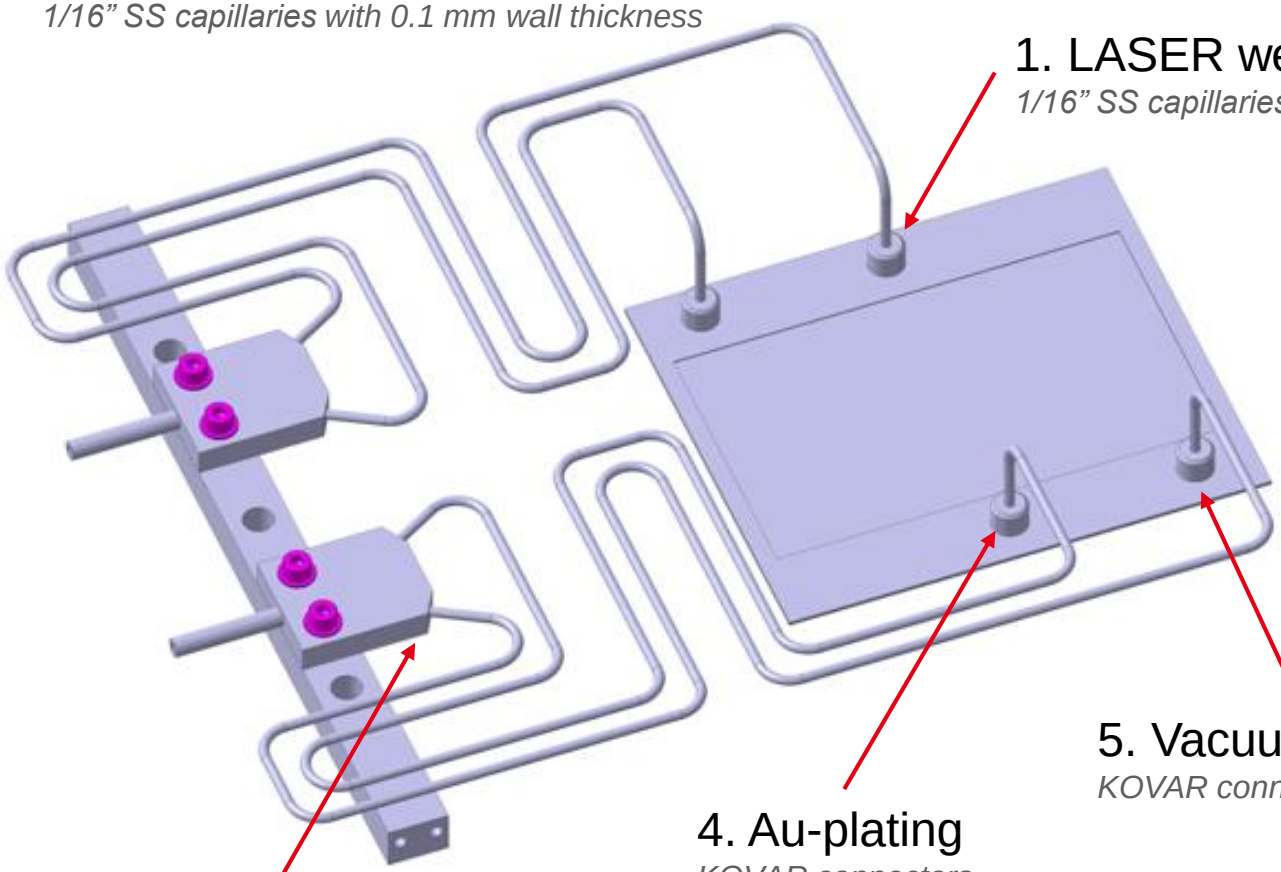
NA62-GTK – SOLDERING OF CONNECTORS

2. Bending of the capillaries

1/16" SS capillaries with 0.1 mm wall thickness

1. LASER welding

1/16" SS capillaries to KOVAR connectors



5. Vacuum brazing

KOVAR connectors do Si

4. Au-plating

KOVAR connectors

3. NICROBRAZ brazing

1/16" SS capillaries to SS manifolds

ROADMAP FOR PROGRESS

A NETWORK TO COORDINATE THE EFFORTS:

- **microfab**

  silicon direct bonding… critical step for pressurized channels!
  - buried channels: complex channels in silicon without bonding?
  - additive manufacturing: working devices in ceramic (~matching CTE)?

- **connectors**

  machined metallic connector brazed on silicon: OK. Better alternatives?
  - 3D printed connectors: Polymeric / Metallic / Ceramics

- **thermo-fluid dynamics data for models**
  - fundamental studies on CO_2 evaporation in microchannels
  - performance studies on prototype silicon devices in single phase flow
  - performance studies on prototype silicon devices in two-phases flow

FBK-CERN EMBEDDED CHANNELS

WAFER BONDING APPROACH

Low material budget microfabricated cooling devices for particle detectors and front-end electronics

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[b]Laboratoire de Microsystèmes, Ecole Polytechnique Fédérale de Lausanne, Switzerland
[c]CP3, Université catholique de Louvain, Louvain-la-Neuve, Belgique

Nuclear Physics B (Proc. Suppl.) 215 (2011) 349–352

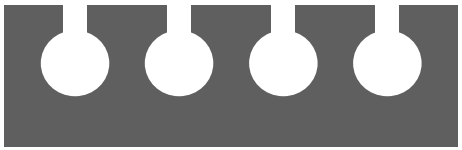
BURIED CHANNELS APPROACH

Silicon buried channels for pixel detector cooling

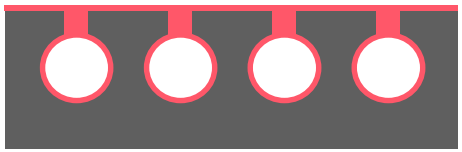
M. Boscardin [a,*], P. Conci [a], M. Crivellari [a], S. Ronchin [a], S. Bettarini [b,c], F. Bosi [c]
[a] Fondazione Bruno Kessler Trento, Via Sommarive 18, I-38123 Trento, Italy
[b] Universitá di Pisa, L.go B. Pontecorvo 3, I-56127 Pisa, Italy
[c] Istituto Nazionale di Fisica Nucleare, Sez. di Pisa, L.go B. Pontecorvo 3, I-56127 Pisa, Italy

Nuclear Instruments and Methods in Physics Research A 718 (2013) 297–298

trenches - anisotrpic etch



channels - isotropic etch



trench filling

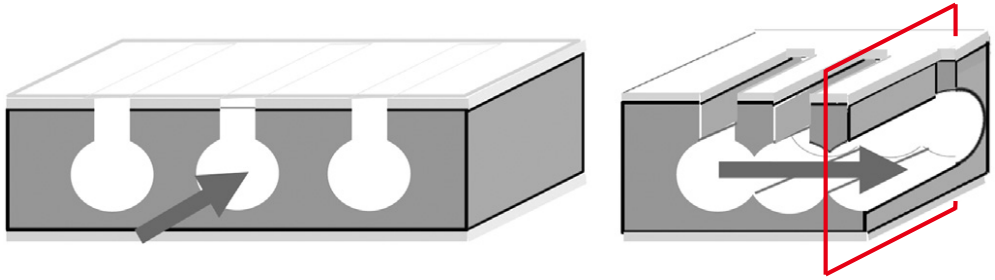
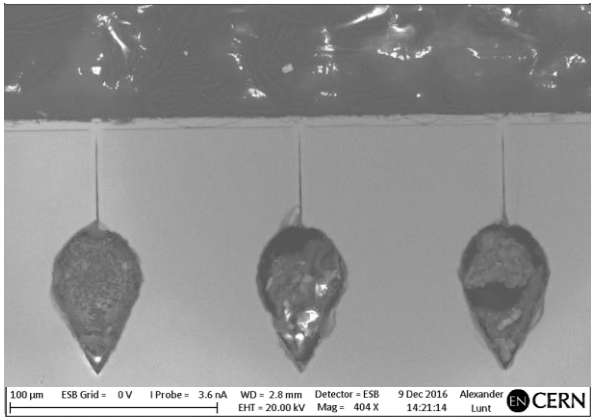
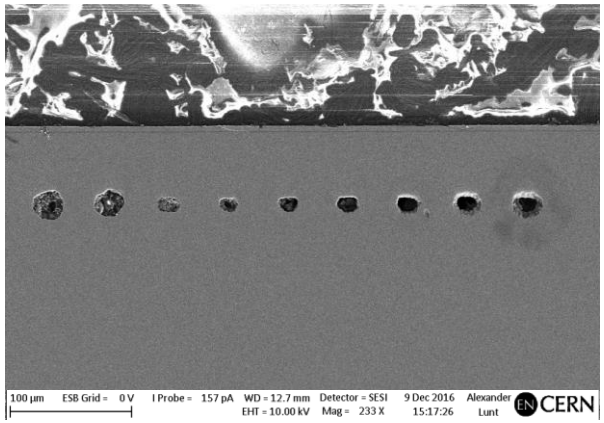
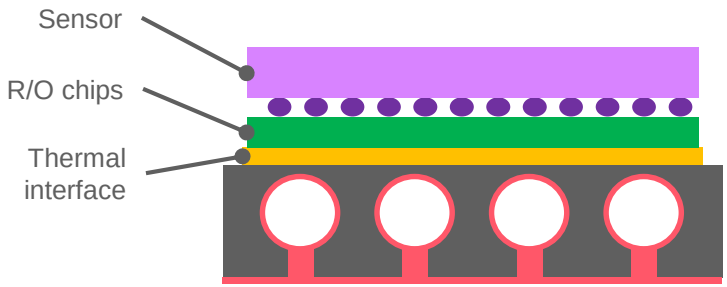


Fig. 1. Process sections for longitudinal and transverse channels.

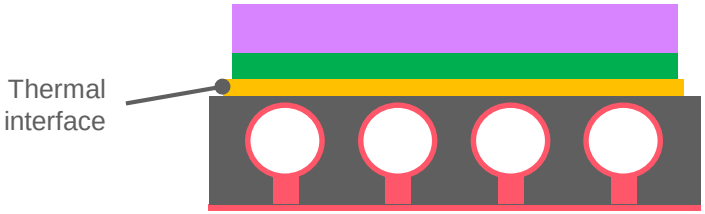




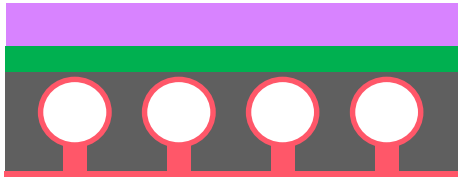
TOWARDS FULL INTEGRATION…?



Hybrid sensor on cooling plate



Monolithic sensor on cooling plate



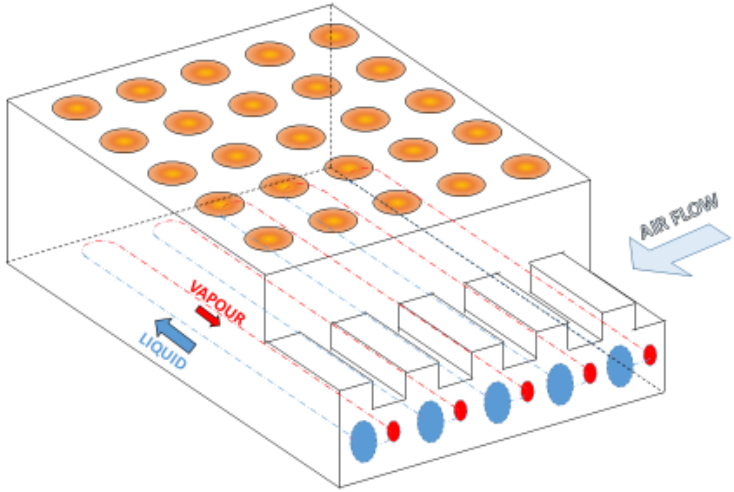
Monolithic sensor with embedded microchannels

Integrated, autonomous solutions for thermal management in high energy physics and space applications

D. Alvarez Feito[1], M. Boscardin[2], A. Mapelli[1], P. Petagna[1]

[1]*CERN EP-DT, Experimental Physics Department, Detector Technologies Group, Geneva, Switzerland*

[2]*FBK, Fondazione Bruno Kessler, Trento, Italy*

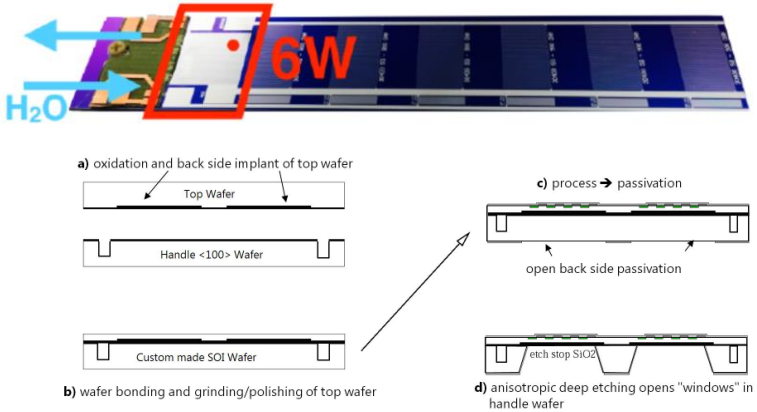


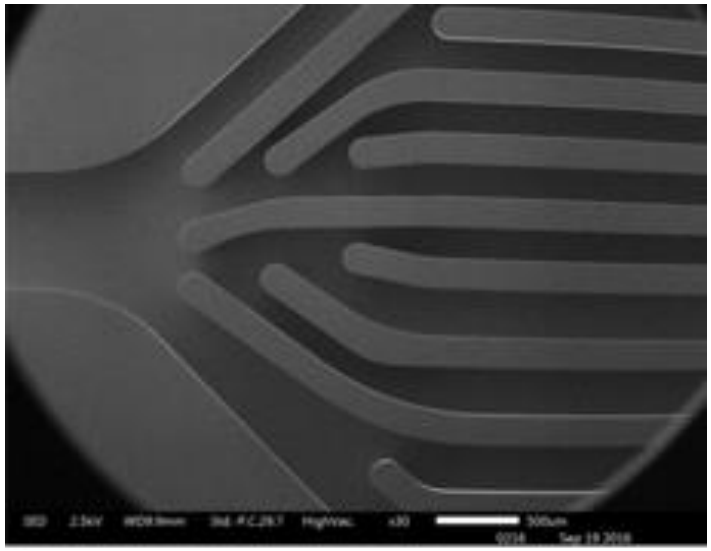
OTHER ALTERNATIVES UNDER STUDY

Valencia-Bonn-Munich:

SOI substrate with embedded DRIE channels

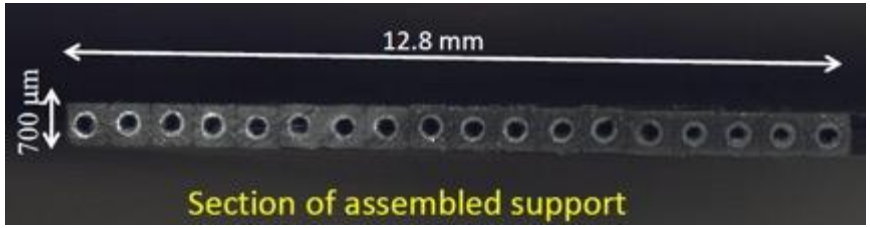
see also: 2016 JINST 11 P06018

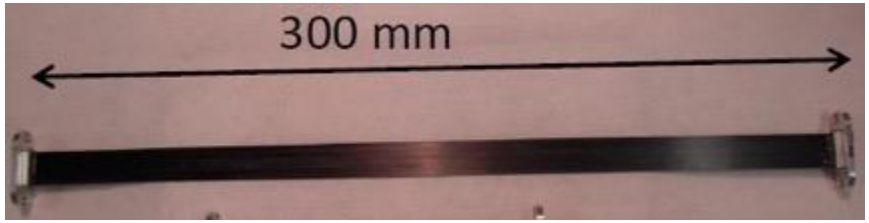




Pisa:

PEEK+CFRP pultruded pipes array

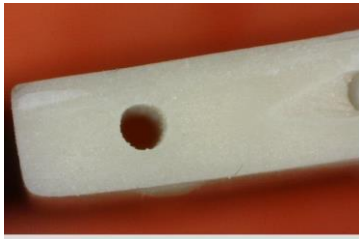




Images courtesy of A. Messineo and F. Bosi

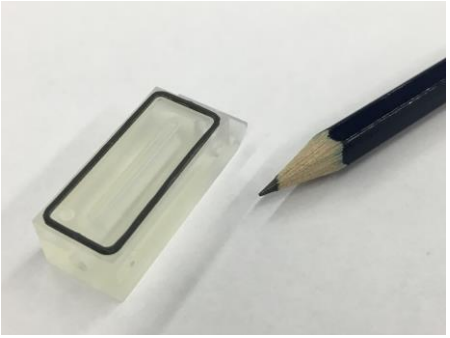
CERN + Manchester (+ industry):

3D printed ceramic channels demonstrators

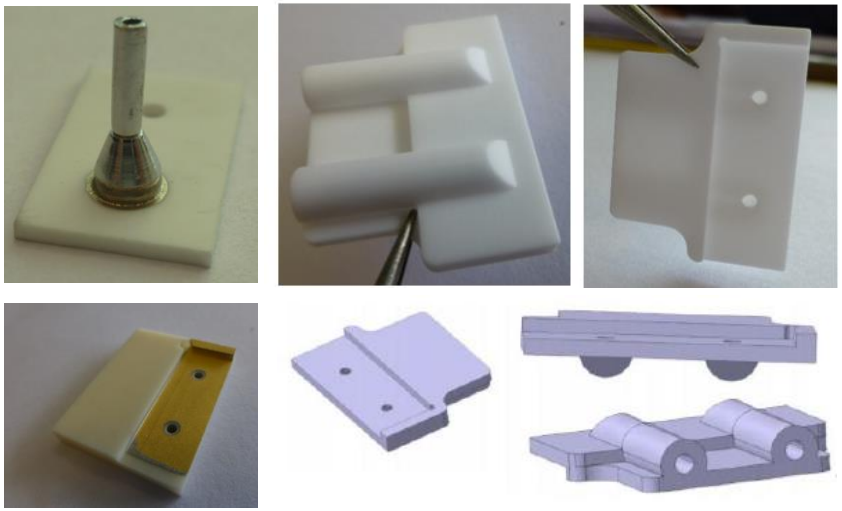


MINIATURE 3D-PRINTED CONNECTORS

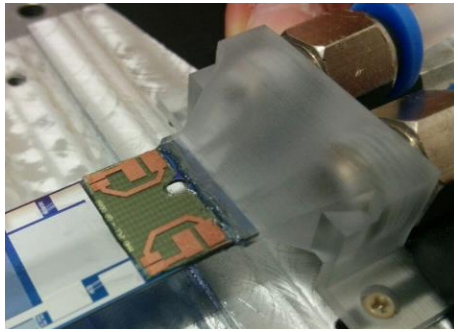
CERN (Polymer)



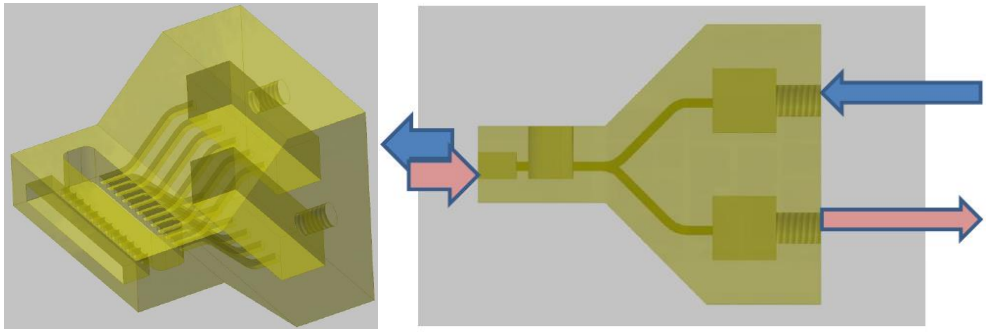
CERN + Manchester (Ceramics)



Valencia (Polymer)



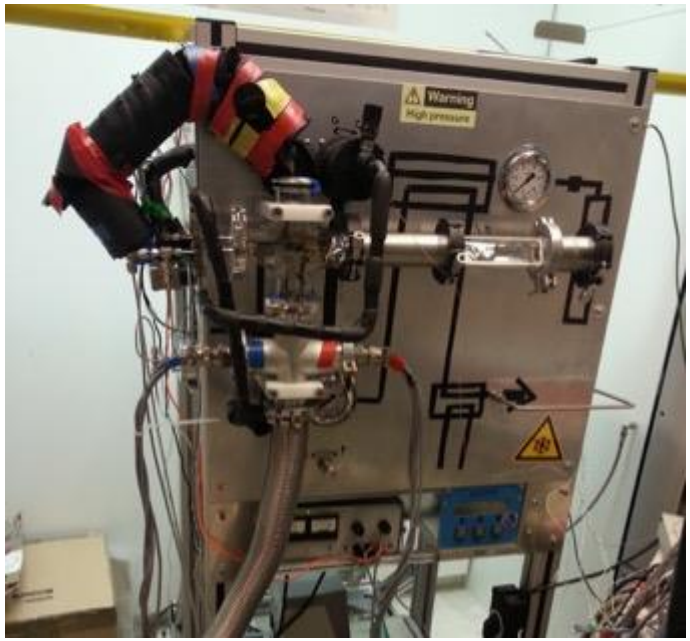
Pisa (design ready for metal or polymer)



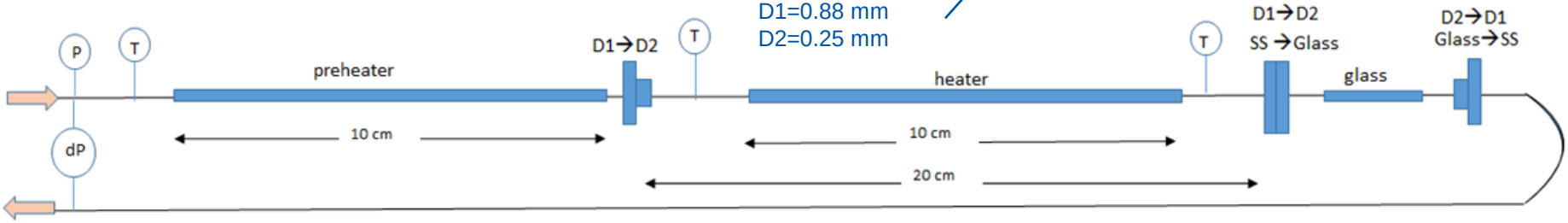
MICROCHANNEL STUDIES AT TWENTE

A. Koutoulaki (UT, Nikhef), Marcel Ter Brake (UT), Harry Holland (UT)

- CO_2 Blow system with by-pass extension
- Temperature and pressure measurements
- High speed camera for flow visualization
- Fixed circular pipe diameter: 250 μm
- Fixed evaporation temperature: -20ºC
- Measurement matrix:
  - heating power variation
  - mass flow variation
- Next step: silicon multichannel device (provided by CERN)



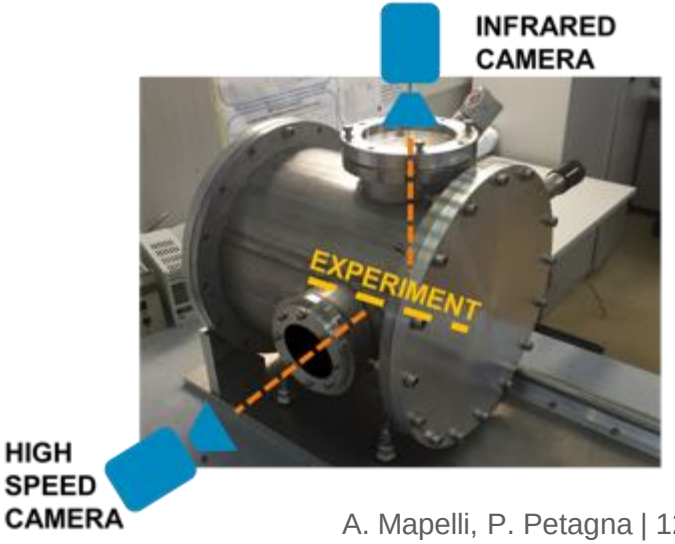
Inner diameters:
D1=0.88 mm
D2=0.25 mm



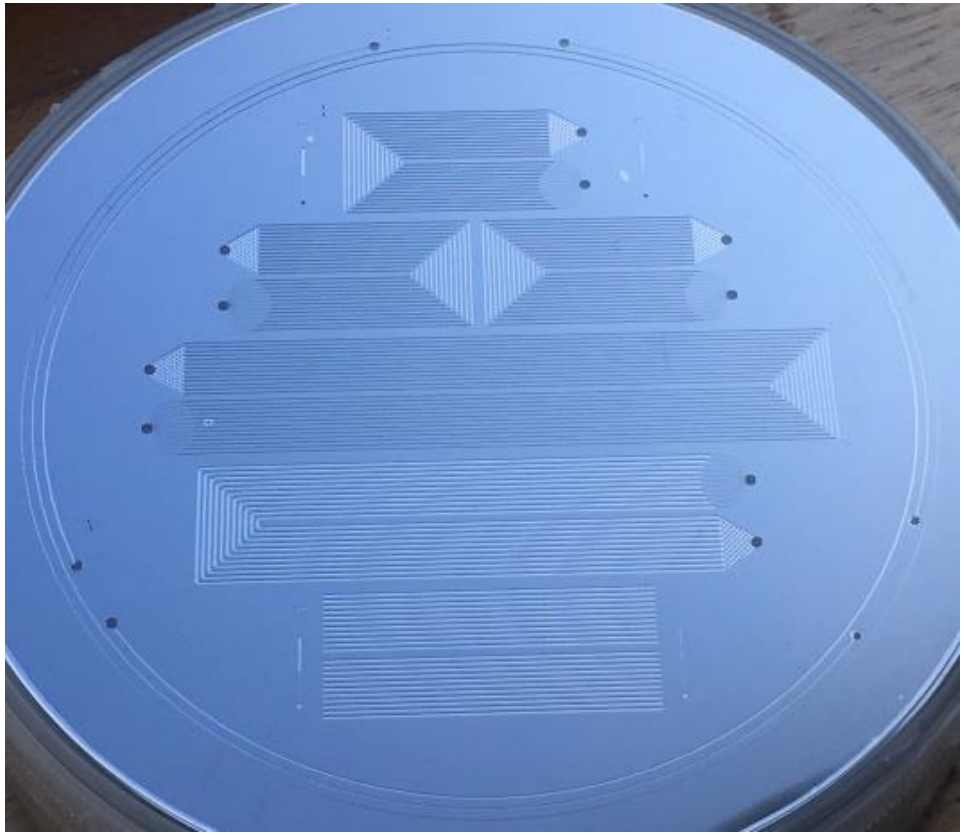
CO_2 TEST SETUP AT CERN

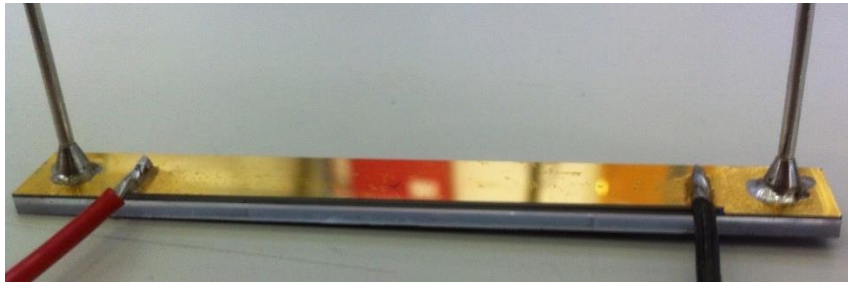
- Controlled CO_2 recirculation cooling unit
- Test setup fully under vacuum
- Temperature and pressure measurements
- High speed camera for flow visualization
- Infrared camera for thermal visualization
- Deliverable of Task 9.2 due in October 2017 - on schedule.

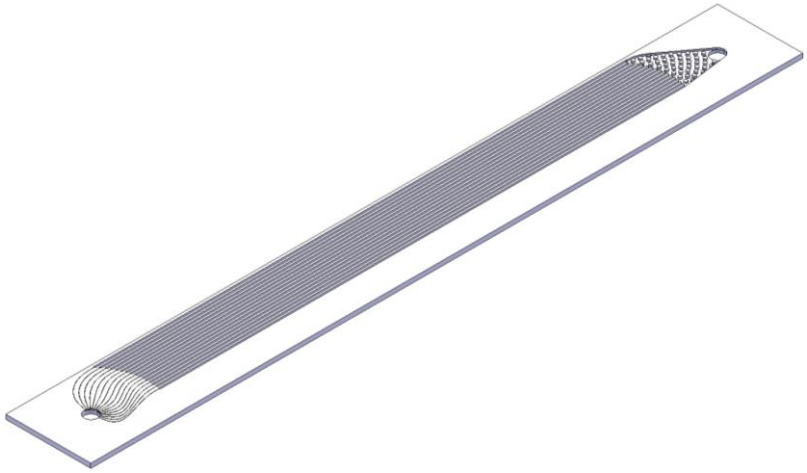
- Study boiling at the microscale level in simple single channels and tubes.
  - Glass, Stainless Steel, Titanium, Silicon
  - Round ID: 0.1 – 1.0 mm
  - Square Dh: 0.1 - 0.8 mm
- Test complex microchannel layouts in silicon substrates designed for HEP experiments.



MICROCHANNELS FOR BI-PHASE CO_2 STUDIES



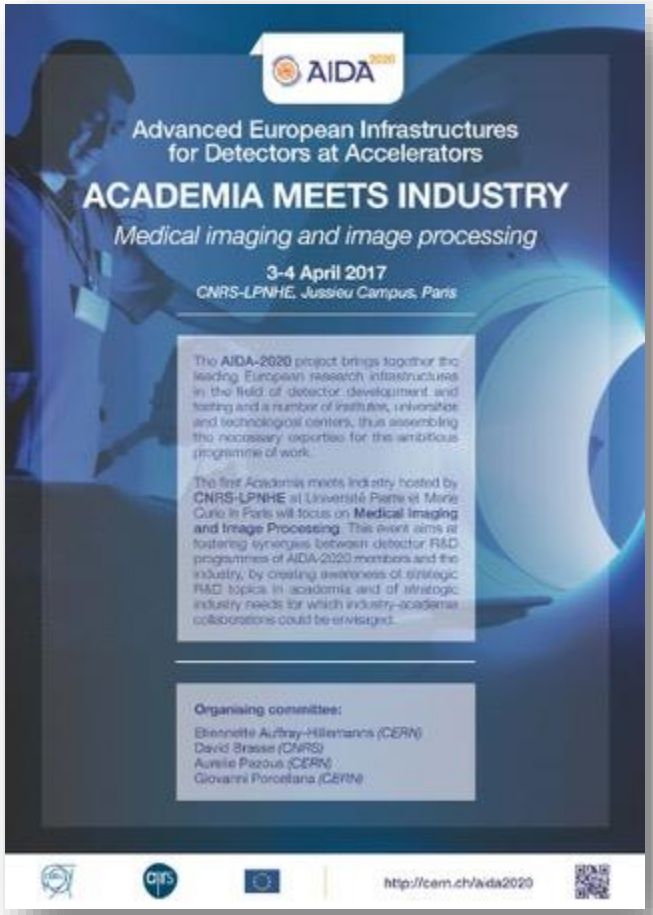




CONCLUSIONS & OUTLOOK

SCOPE OF AIDA-2020 TO GATHER THIS KNOWLEDGE AND BRING BUILDING BLOCKS TOGETHER

- **Thermal management** represents a major challenge in HEP.
- Continuous **advances in micro-engineering** have opened the door to the development of smaller and more efficient cooling devices capable of handling increasing power densities with a minimum mass penalty.
- AIDA-2020 is bringing together a **community** to develop and study silicon microchannel cooling devices and low mass mechanical structures .
- By 2019, a catalog of **building blocks**, **design guidelines** and **standards for characterization and qualification** of devices and systems for microchannel cooling (single phase and evaporative) will be available.



AIDA-2020 Academia Meets Industry event

- During the AIDA-2020 Annual Meeting
- 3rd-4th April 2017 (Mon-Tue)
- At CNRS-LPNHE, Jussieu Campus in Paris
- Topic: Medical imaging and image processing

Speaker applications welcomed

Send applications to:
AIDA-2020-info@cern.ch

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CERN