PH-DT
Detector Technologies

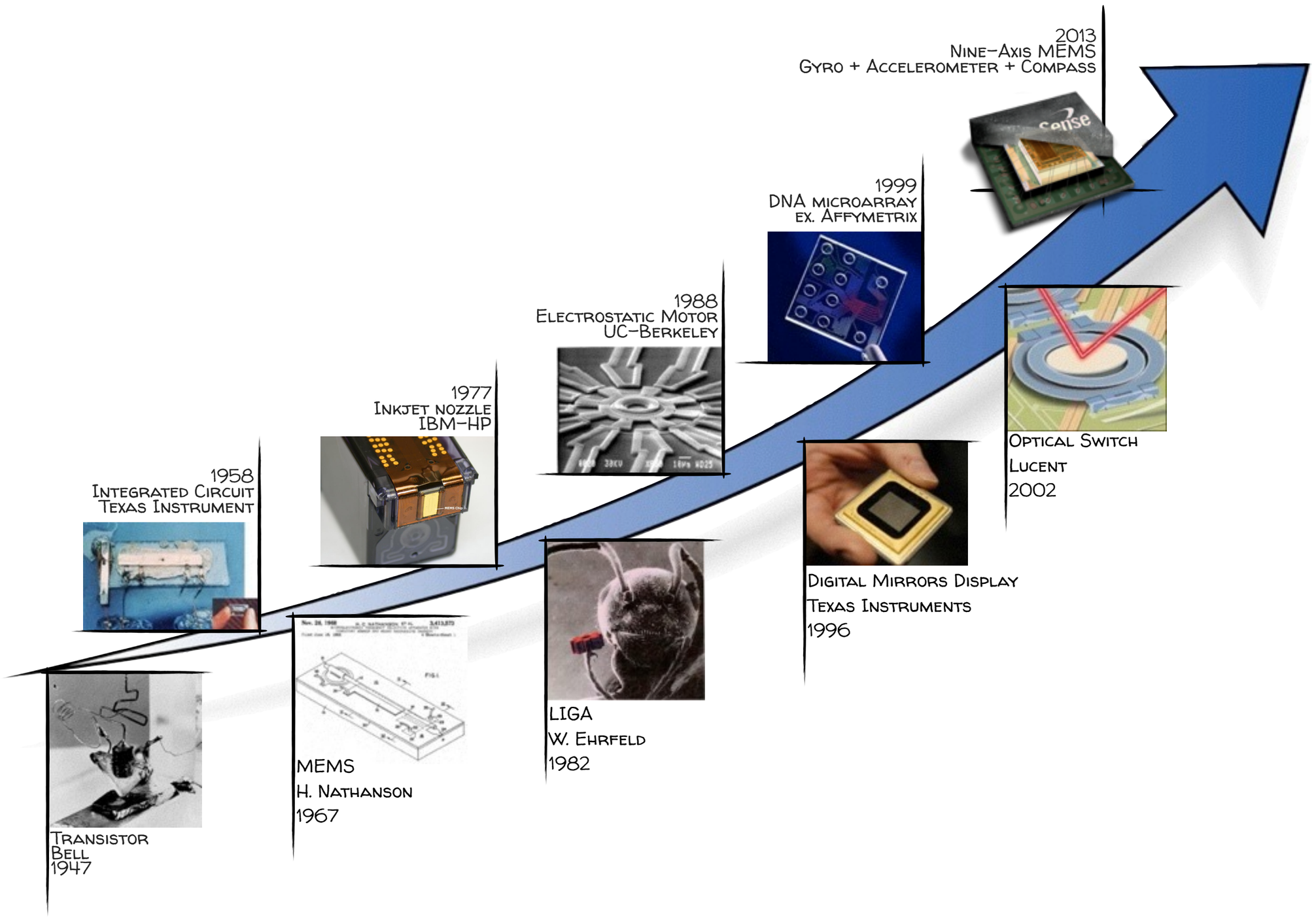
Microfabrication in PH-DT

Alessandro Mapelli
PH-DT-EO

FROM MICROFLUIDIC SCINTILLATION DETECTORS
TO ON-DETECTOR COOLING SYSTEMS

PH-ESE seminar
CERN, 5 November 2013

Microfabrication Milestones



Microfabrication Techniques

Bulk Micromachining

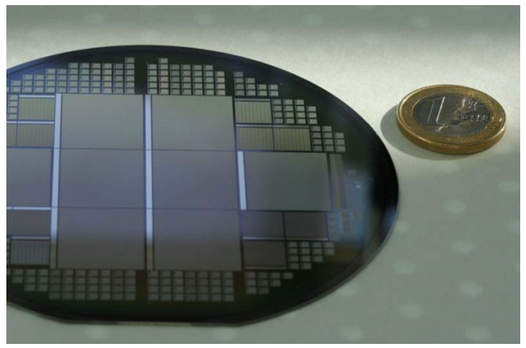
Mechanical structures are etched in the substrate

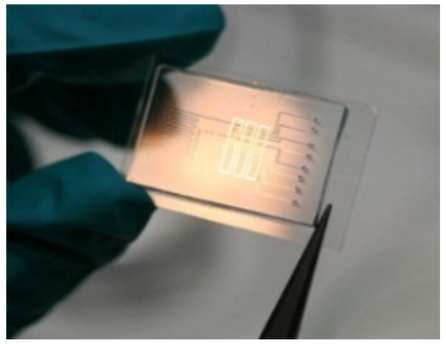
Surface Micromachining

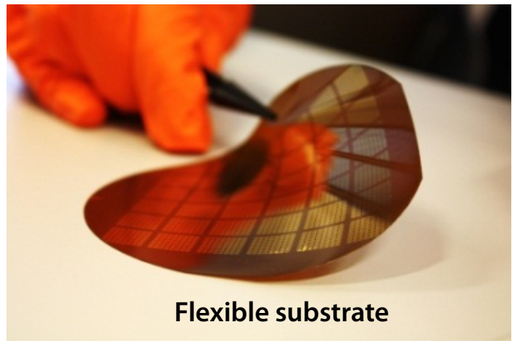
Layers of material are deposited on the substrate,
patterned and selectively removed

Substrates

Round wafers 3", 4", 6", 8", 12"...
Silicon, SOI, glass, GaAs, SiC, Ge, polymers...







2006 2007 2008 2009 2010 2011 2012 2013

MICROSCINT

MICROFLUIDIC SCINTILLATION DETECTORS

MICROHEII

HEAT TRANSFER OF SUPERFLUID HELIUM

MICROCOOL

MICROFABRICATED ON-DETECTOR COOLING SYSTEMS

microtechnologies

particle detectors

@CERN

GIULIA ROMAGNOLI
PIETRO MAODDI
ANDREA FRANCESCON
LUDOVIC SEREX

http://directory.web.cern.ch/directory/

PH Physics

IT Information Technology
BE Beams
TE Technology
EN Engineering
HR Human resources
FP Finance and Procurement
GS General Infrastructure Services

http://ph-dep.web.cern.ch/ph-dep/

ESE : Electronics System for Experiments group
AGS : Administration and General Services
LCD : Linear Collider Detector
ALICE : A Large Ion Collider Experiment
LHCb : The Large Hadron Collider Beauty experiment
ATLAS : A Toroidal LHC ApparatuS
SFT : SoFTware design for experiments group
CMS : the Compact Muon Solenoid experiment
SME : Small and Medium Experiments team

DT : Detector Technologies

TH : THeoretical physics unit
EDU : EDUcational group
TOTEM : TOTal cross section, Elastic scattering and diffraction dissociation Measurement at the lhc

http://ph-dep-dt.web.cern.ch/ph-dep-dt/

DI: Detecior Infrastructure
DD: Detector Development
TP: Technology & Physics

EO: Engineering Office

EM1: Engineering & Mechanics 1
EM2: Engineering & Mechanics 2

@EPFL

http://cmi.epfl.ch/

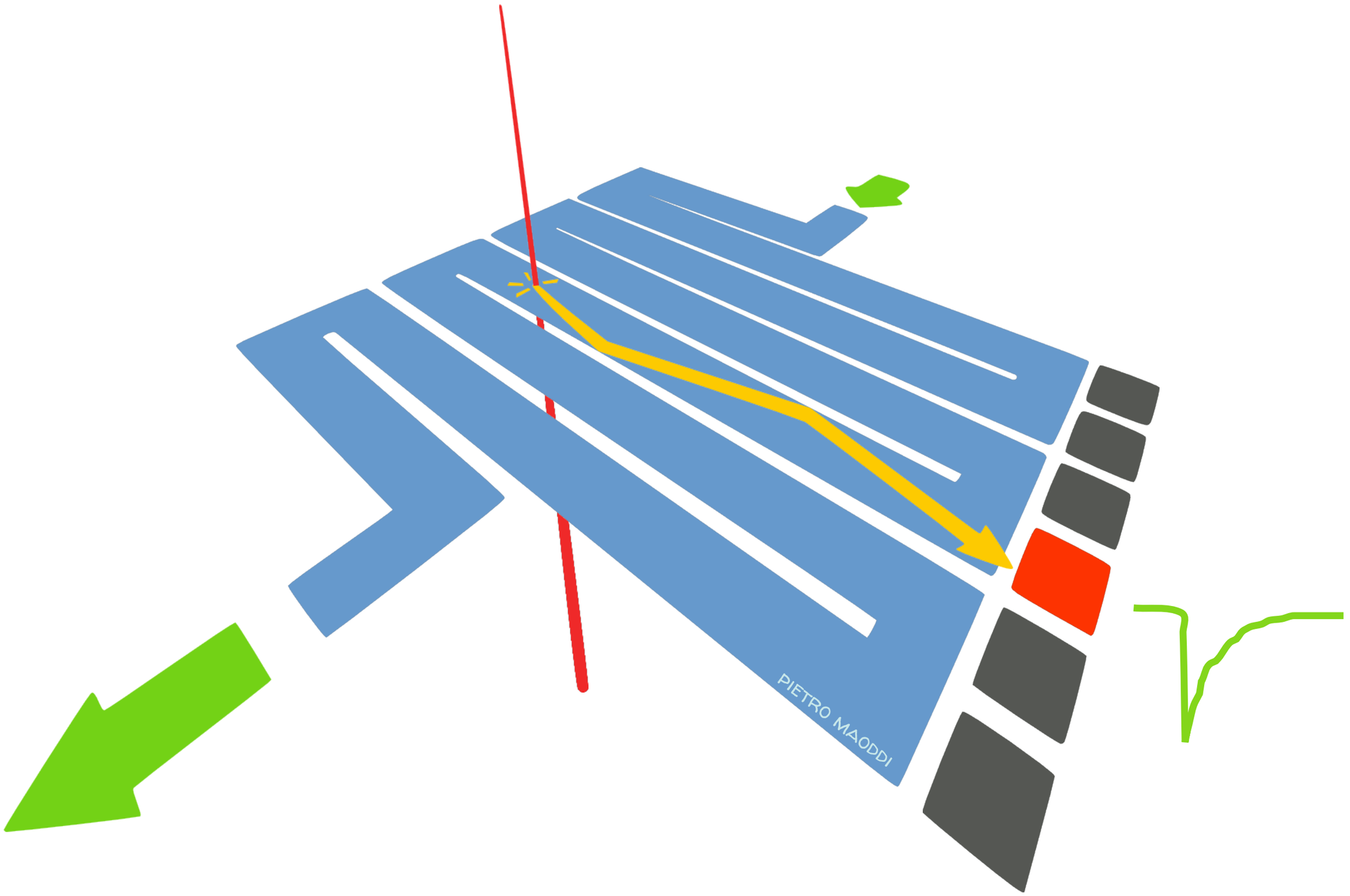
class 100 MEMS cleanroom
- 4" wafers
- (6"wafers)

operation on 50 machines
- Photolithography
- Etching
- Thin Films
- Bonding
- Thinning
- Metrology

output
- 130 photolithography masks
- 1200 wafers processed

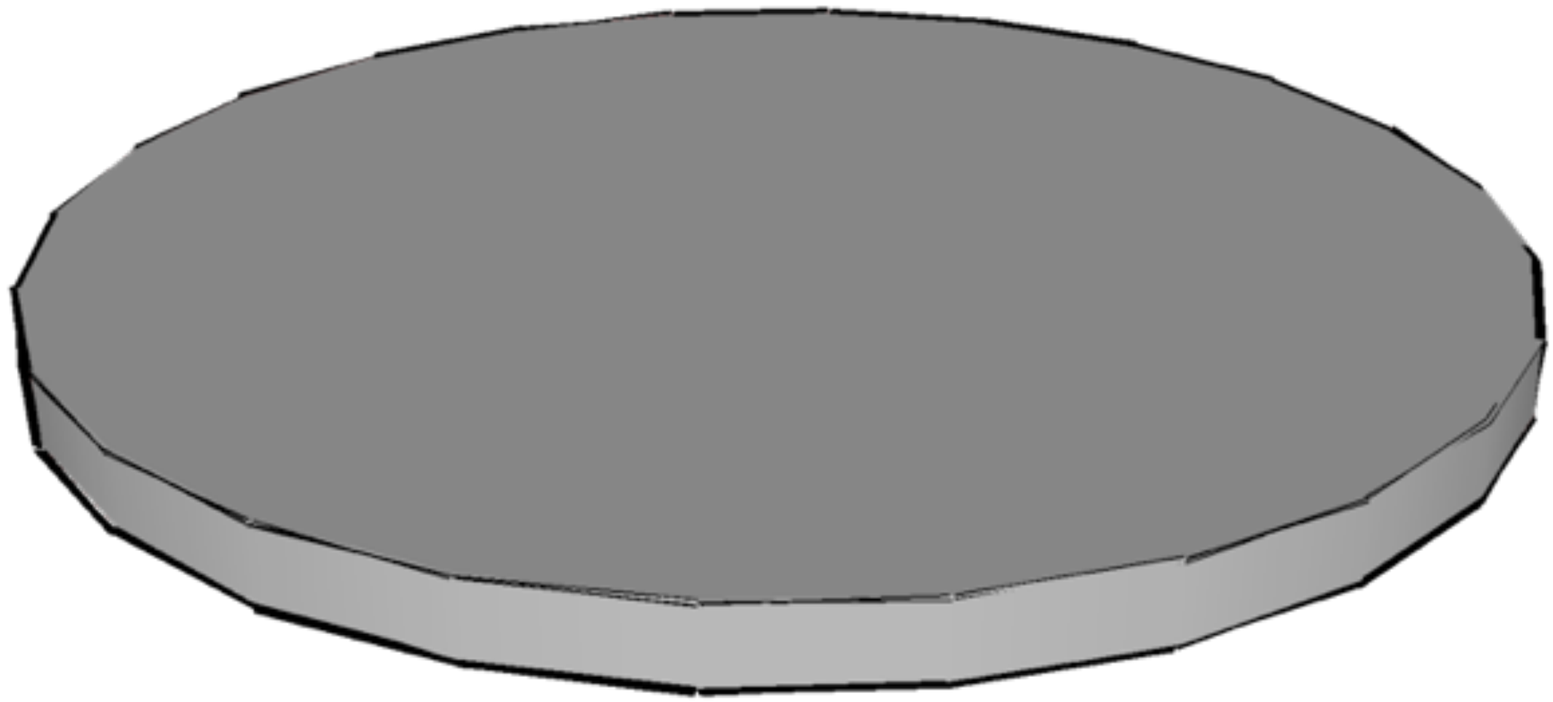
microScint

Development of a **microfluidic scintillation detector** where a single microfluidic channel defines an array of independent optical waveguides to be potentially used as single particle tracker or beam monitor.



first prototype

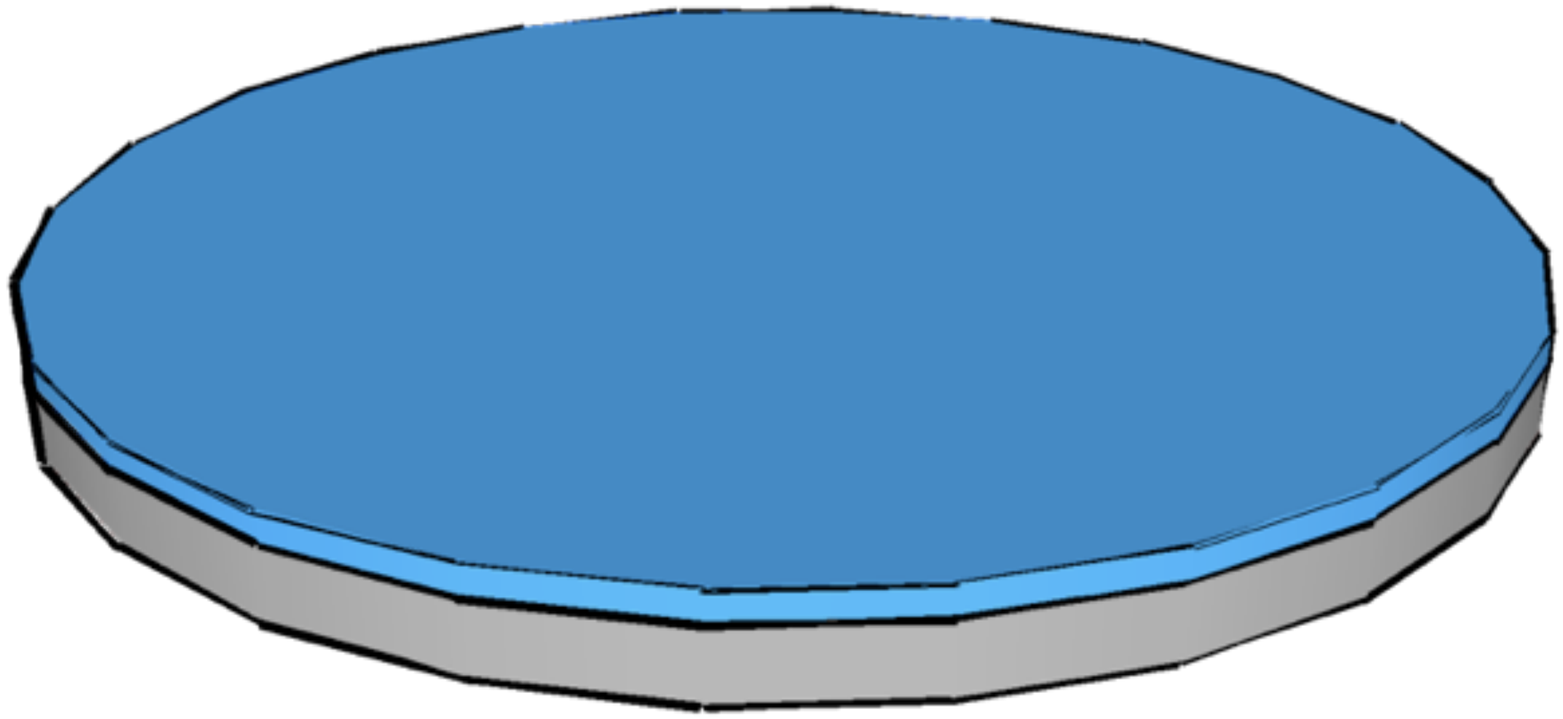
SINGLE PHOTOLITHOGRAPHY STEP TO DEFINE THE CHANNELS
(SURFACE MICROMACHINING)



SILICON SUBSTRATE

first prototype

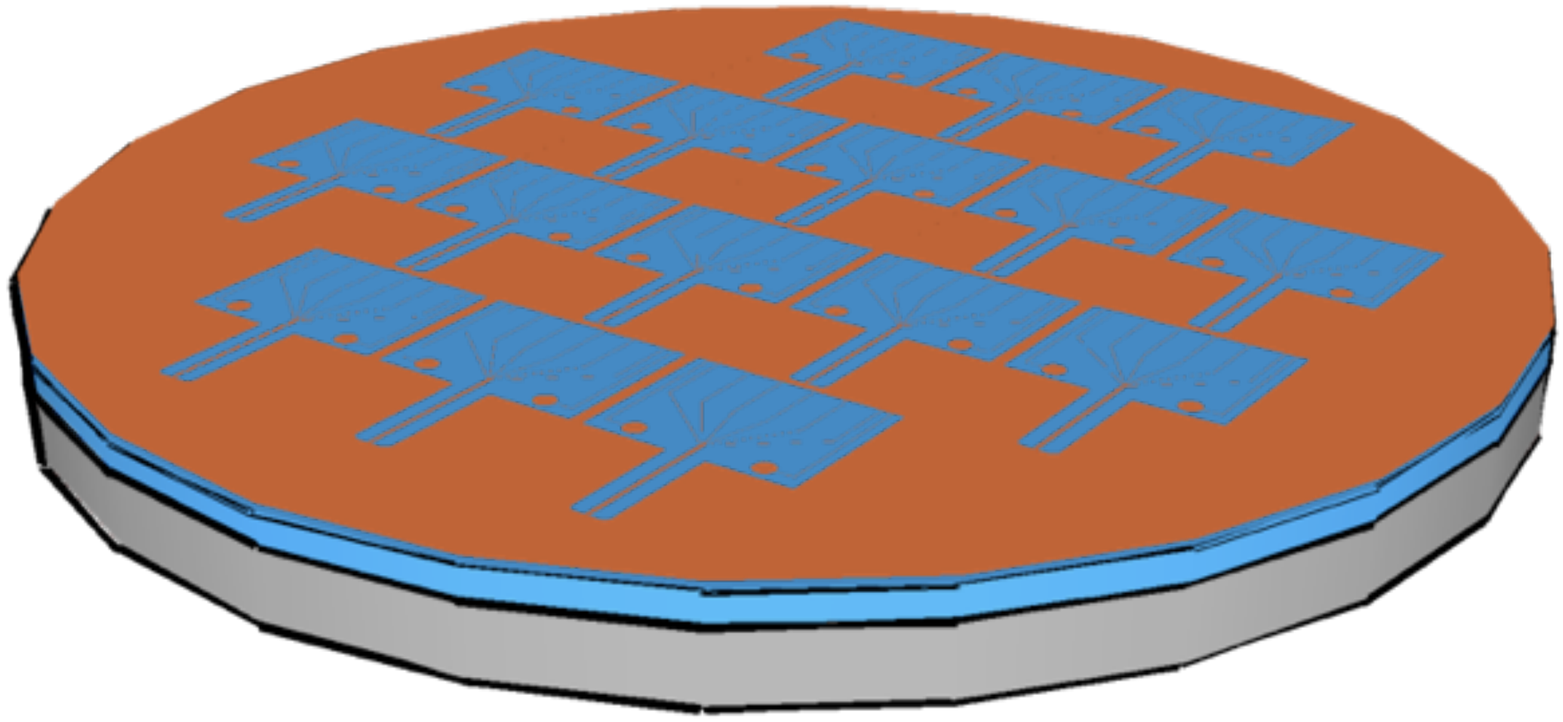
SINGLE PHOTOLITHOGRAPHY STEP TO DEFINE THE CHANNELS
(SURFACE MICROMACHINING)



PHOTORESIST SPIN COATING

first prototype

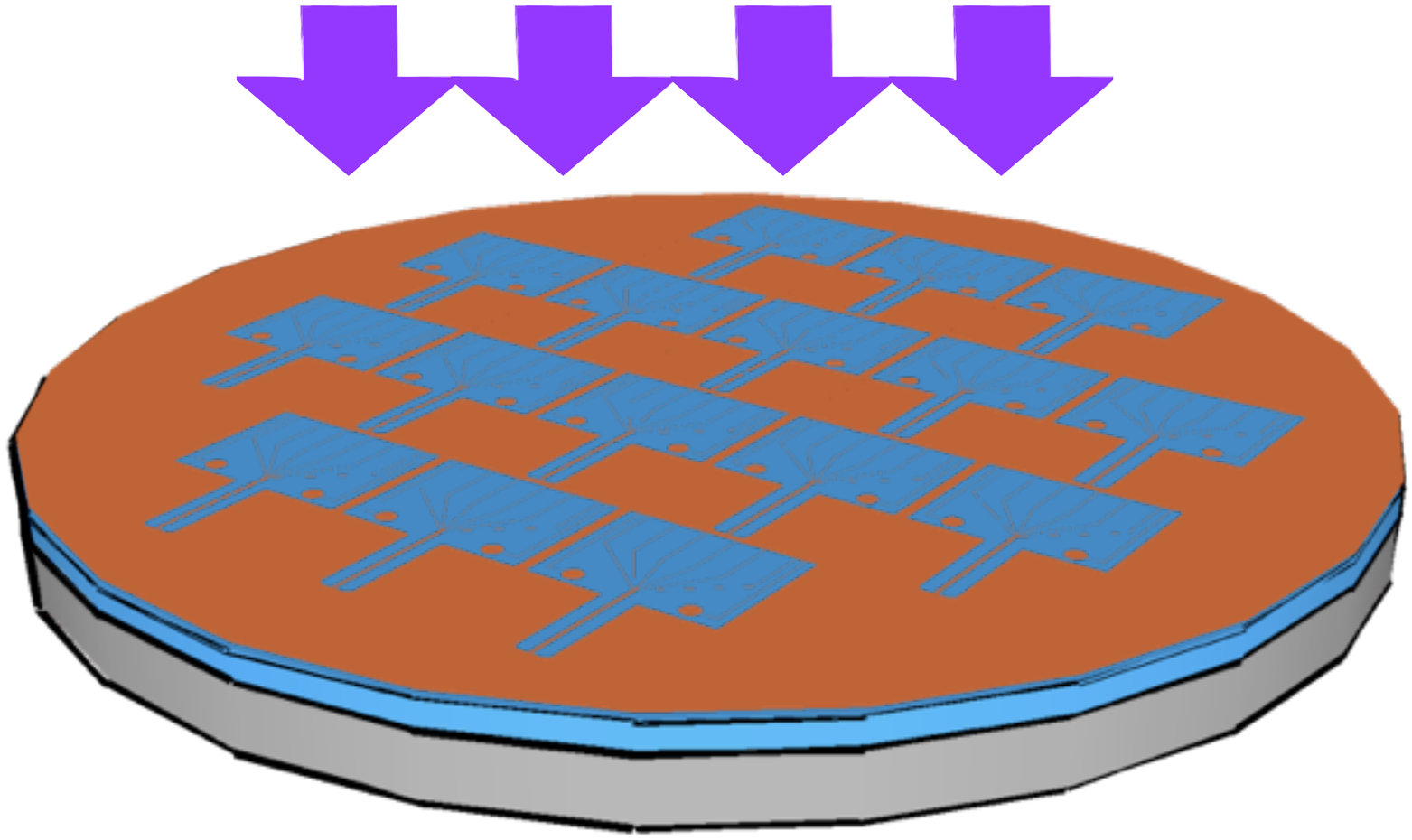
SINGLE PHOTOLITHOGRAPHY STEP TO DEFINE THE CHANNELS
(SURFACE MICROMACHINING)



MASK ALIGNMENT

first prototype

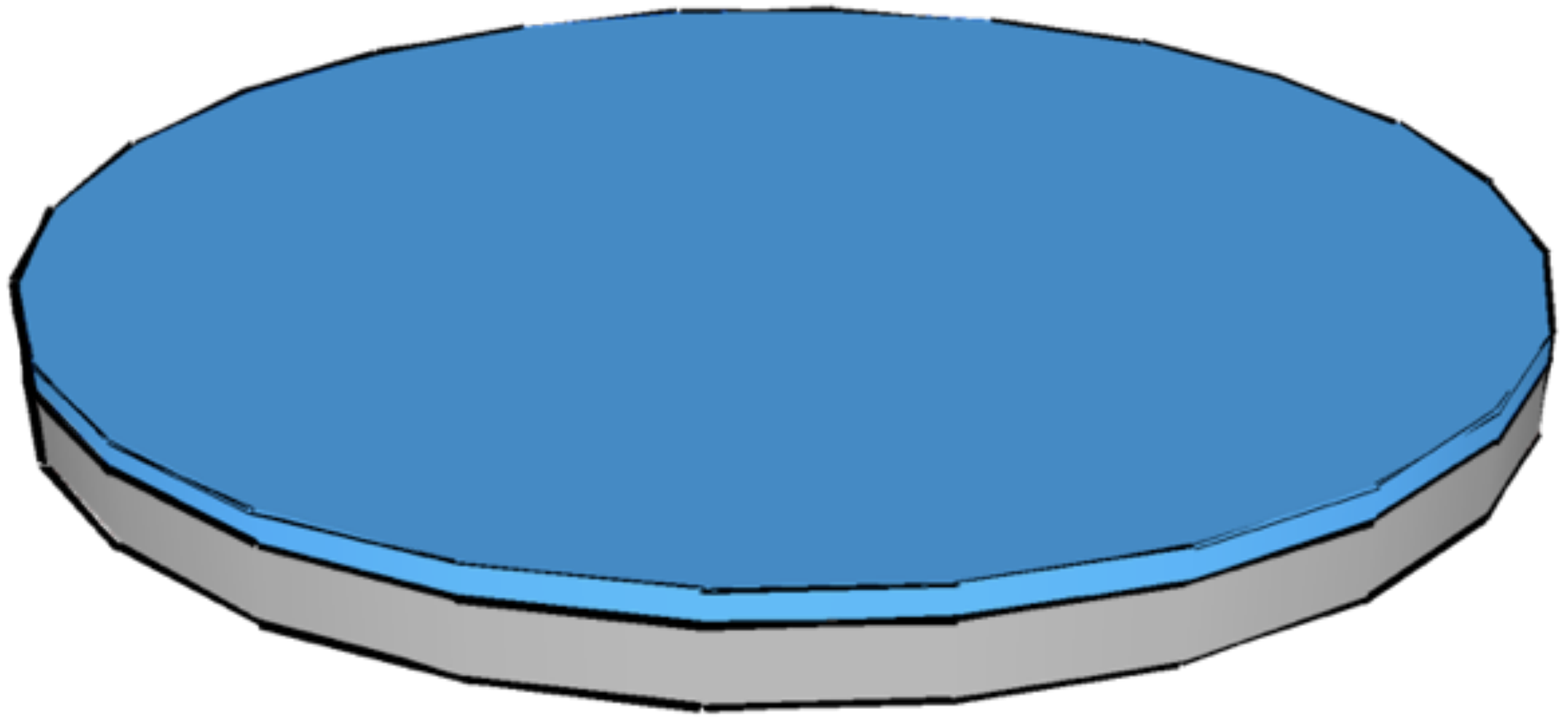
SINGLE PHOTOLITHOGRAPHY STEP TO DEFINE THE CHANNELS
(SURFACE MICROMACHINING)



UV EXPOSURE

first prototype

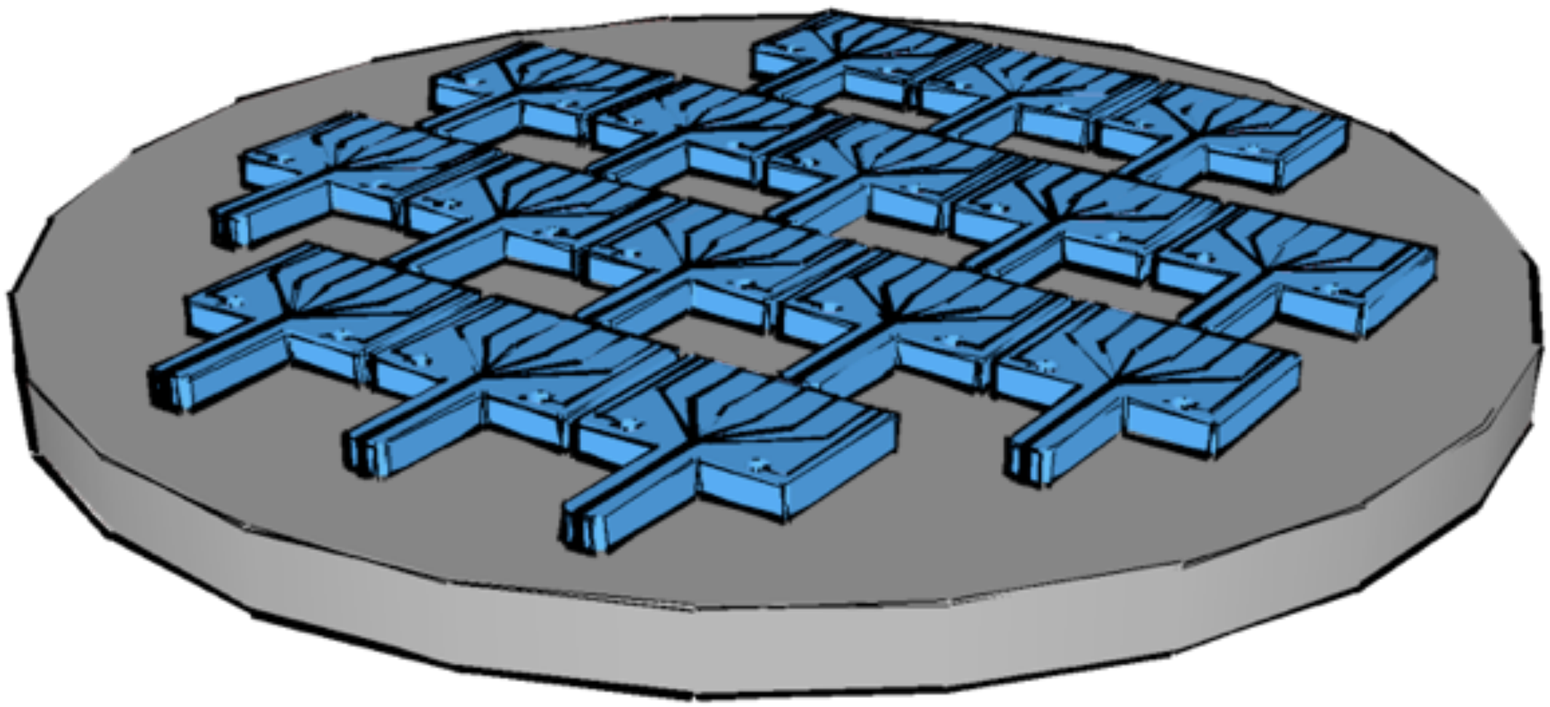
SINGLE PHOTOLITHOGRAPHY STEP TO DEFINE THE CHANNELS
(SURFACE MICROMACHINING)



UV EXPOSURE

first prototype

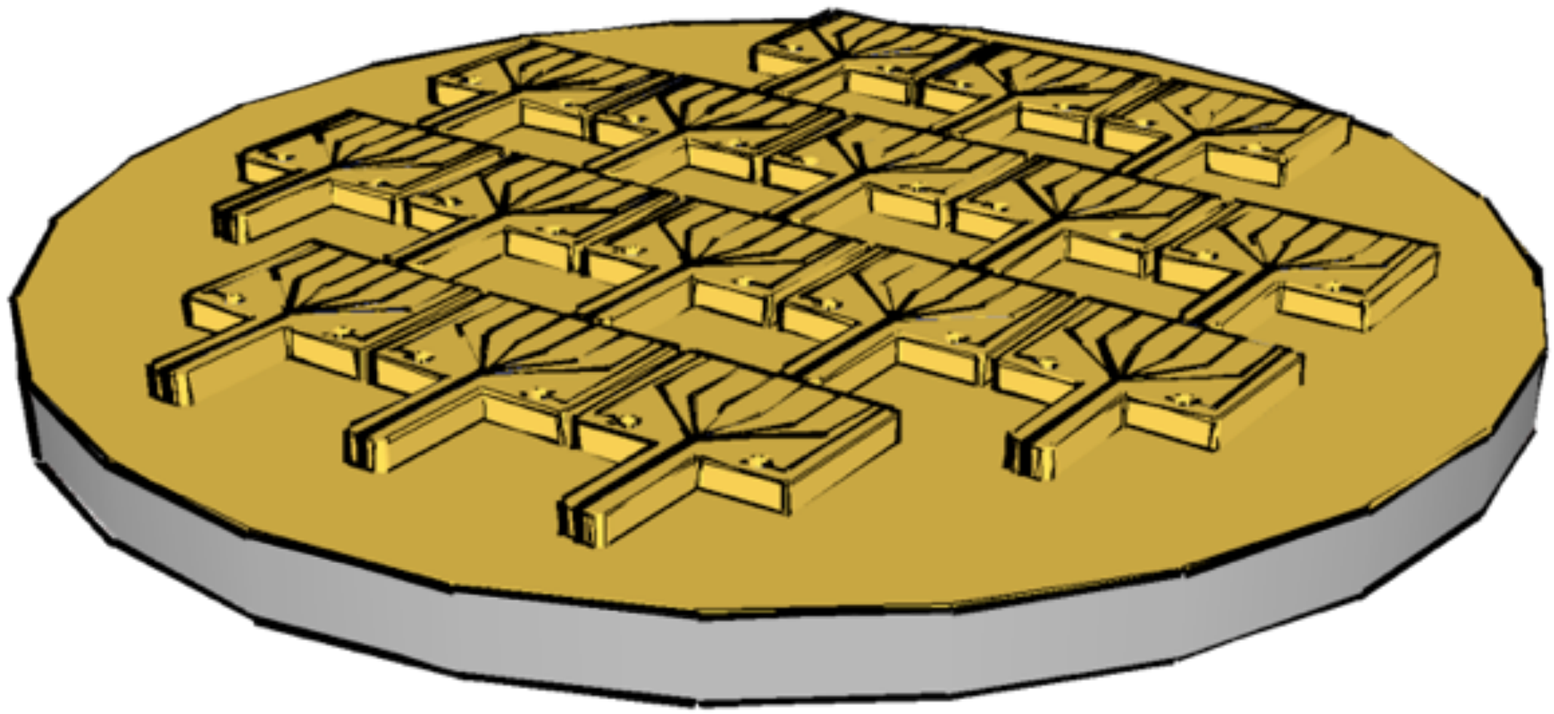
SINGLE PHOTOLITHOGRAPHY STEP TO DEFINE THE CHANNELS
(SURFACE MICROMACHINING)



DEVELOPMENT

first prototype

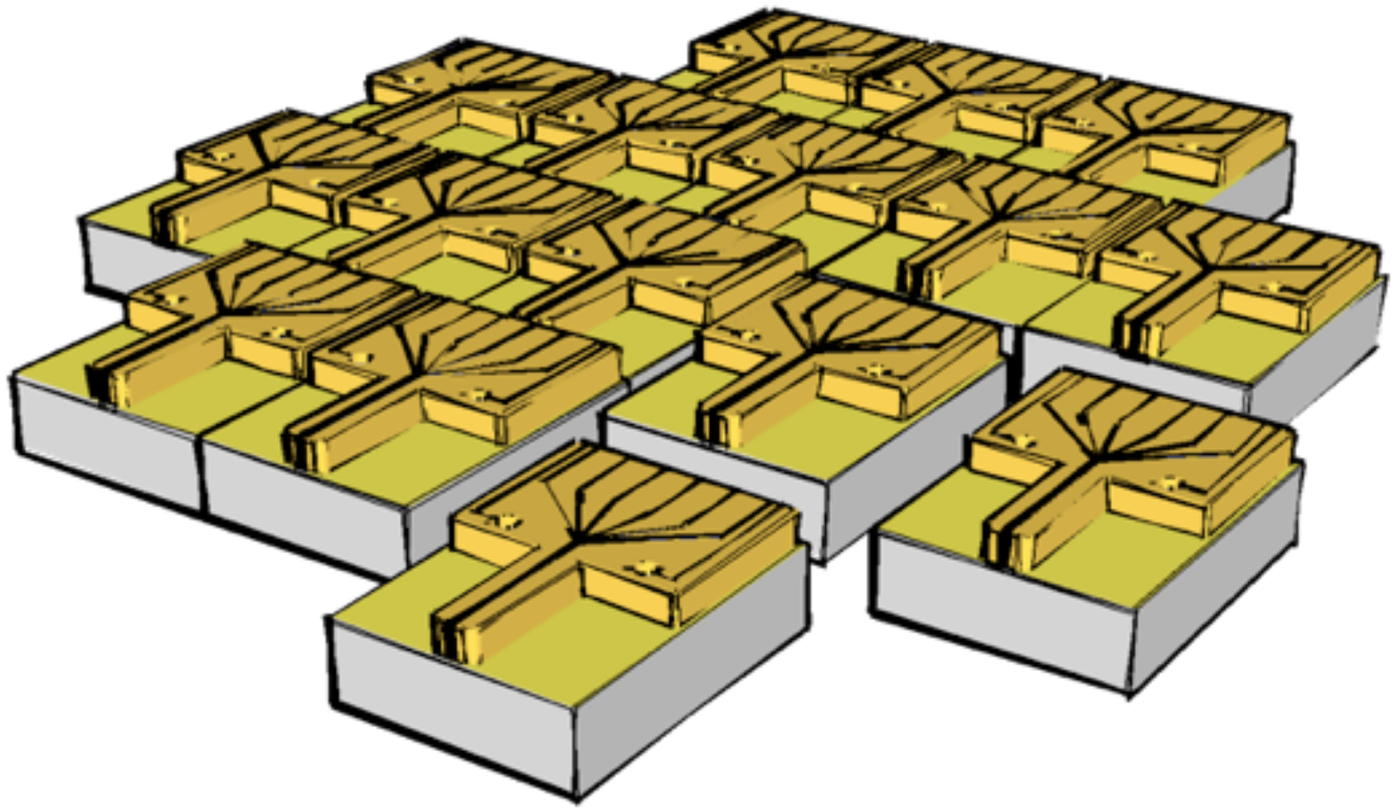
SINGLE PHOTOLITHOGRAPHY STEP TO DEFINE THE CHANNELS
(SURFACE MICROMACHINING)



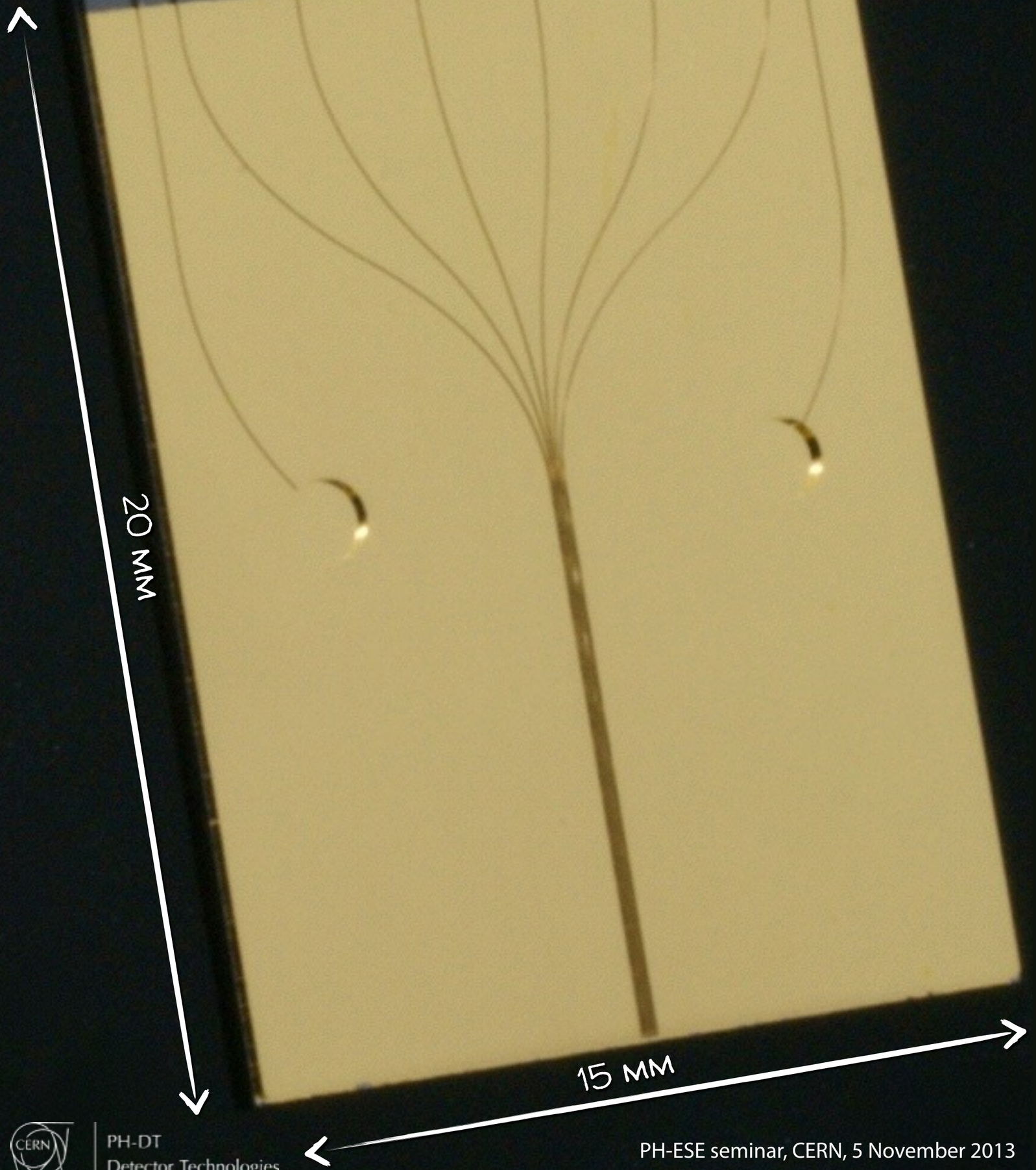
METALLIZATION

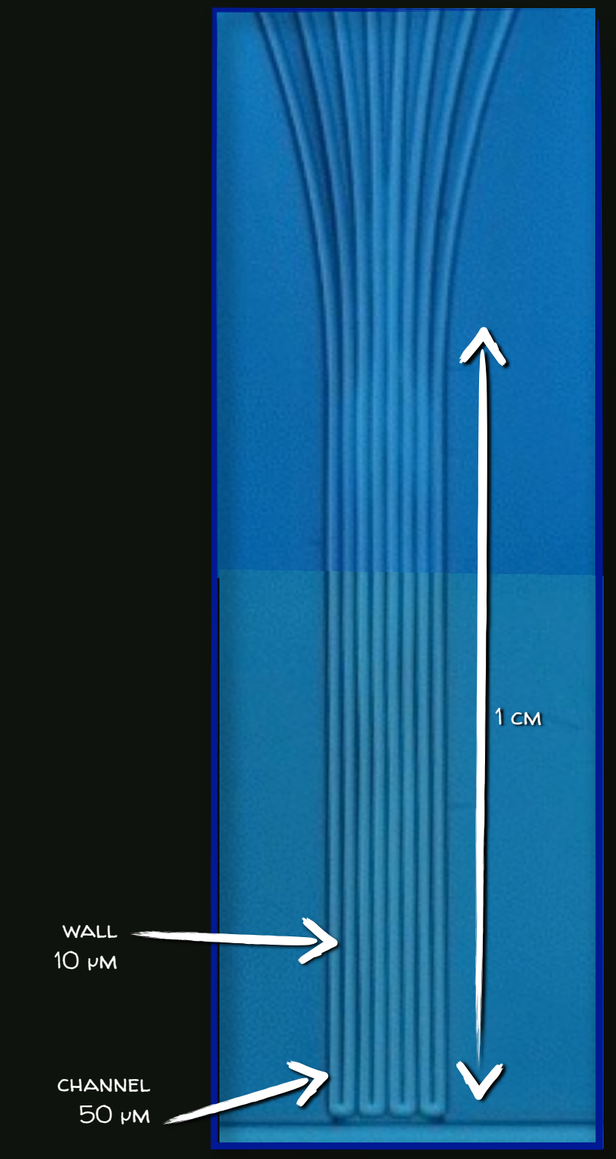
first prototype

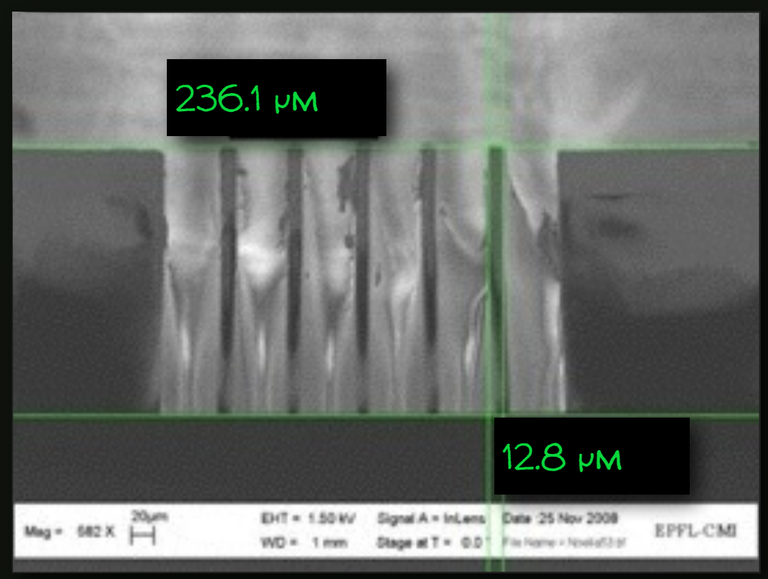
SINGLE PHOTOLITHOGRAPHY STEP TO DEFINE THE CHANNELS
(SURFACE MICROMACHINING)



DICING


20 MM
15 MM

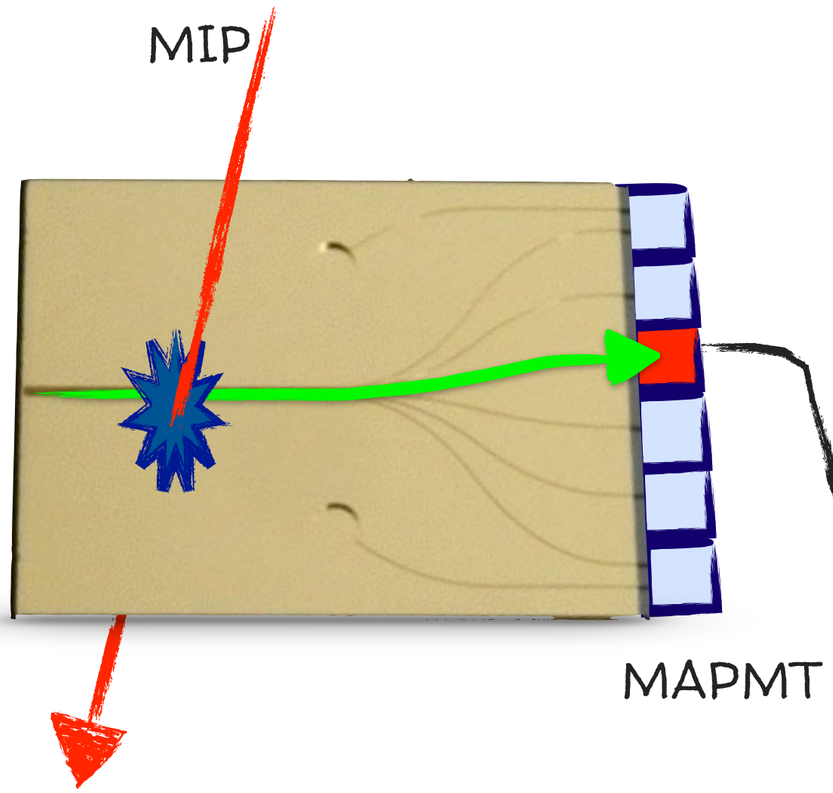

1 CM
WALL
10 µM
CHANNEL
50 µM

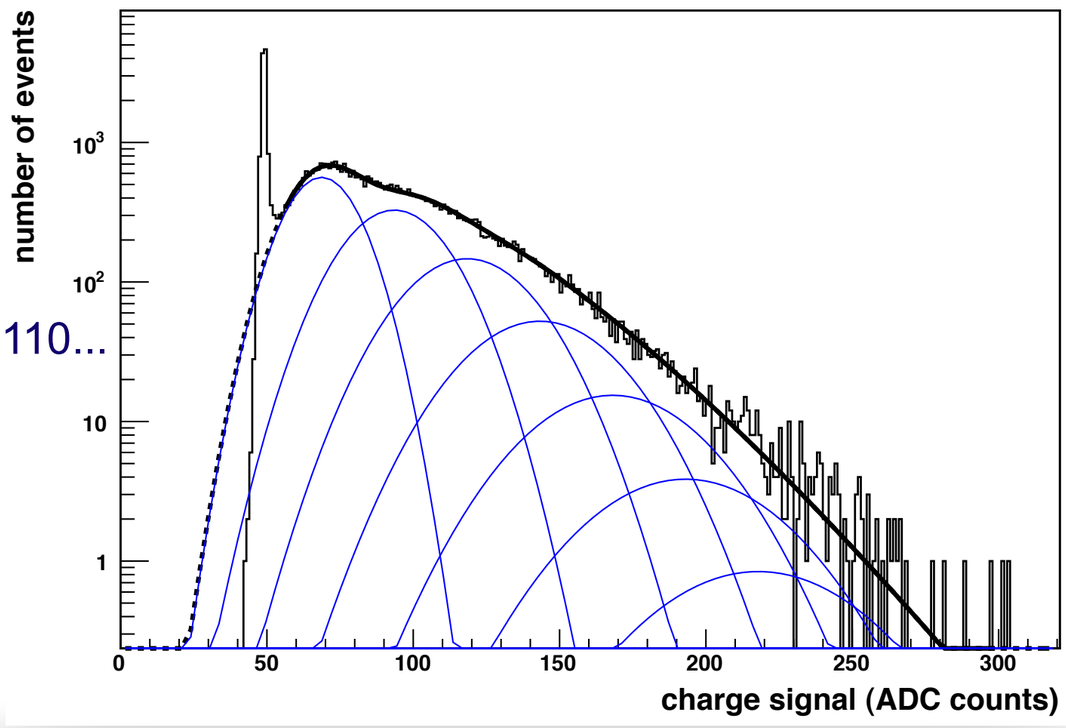

236.1 µM
12.8 µM
Mag = 582 X
20µm
EHT = 1.50 kV
WD = 1 mm
Signal A = InLens
Stage at T = 0.0 °
Date :25 Nov 2008
EPFL-CMI

proof of principle

with 200 μm deep Au-coated SU-8 micro channels

A. Mapelli et al., "Scintillation Particle Detection Based on Microfluidics"
Sensors and Actuators A 162 (2010) 272–275

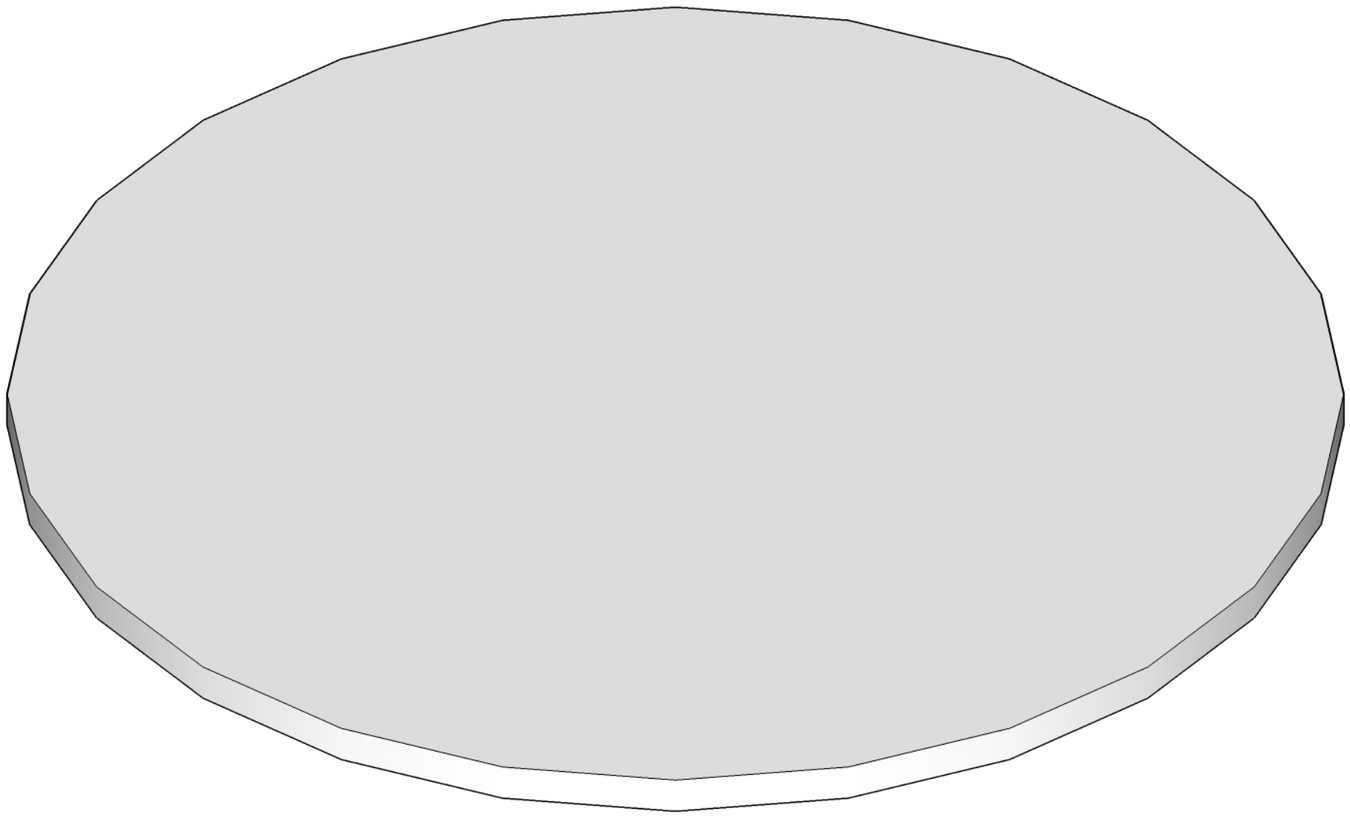




	PLASTICS	MICROSCINT SU-8 Au-COAT
SCINTILLATOR	0.5 MM	0.2 MM
LIGHT YIELD	4.4 PE 9 PE/MM	1.6 PE 8 PE/MM

second prototype

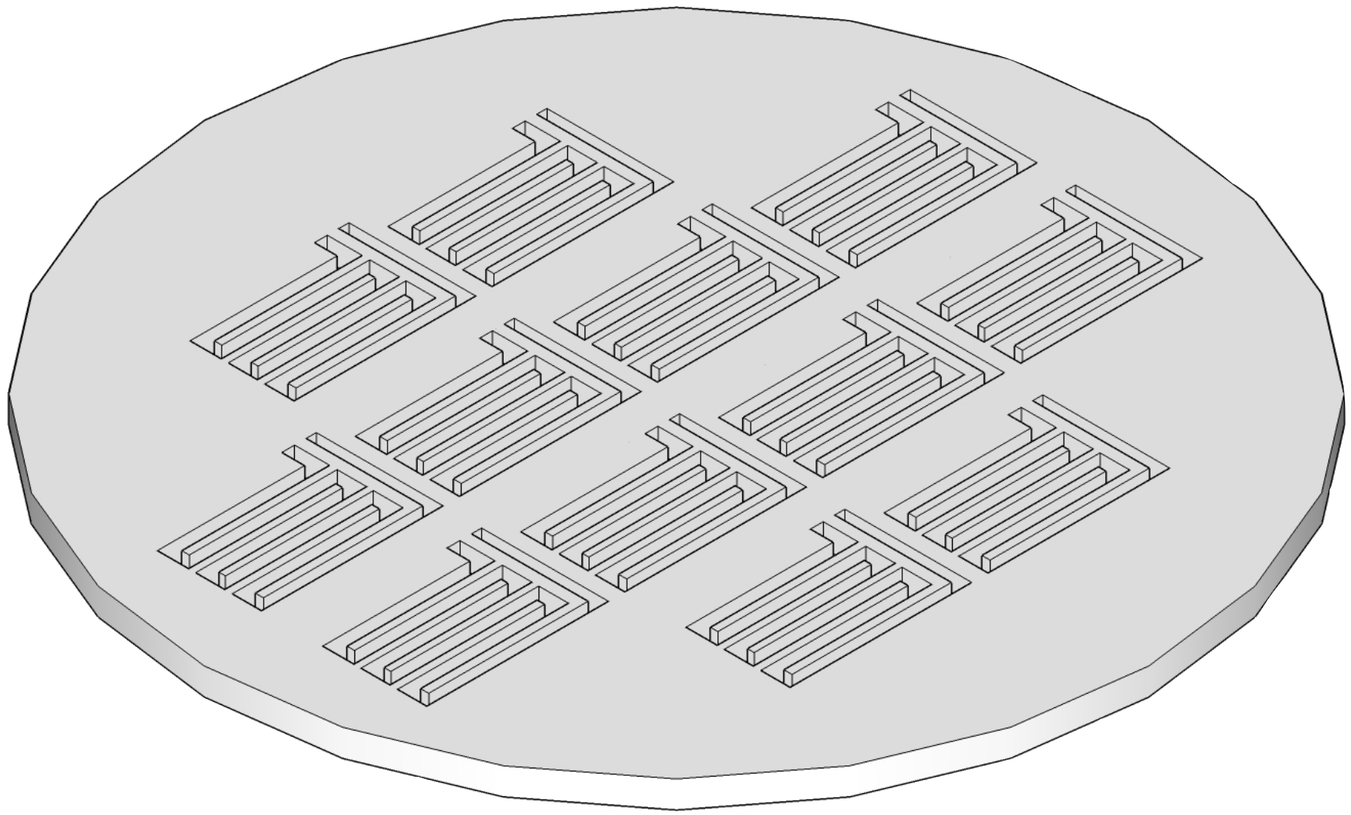
CHANNELS ETCHED IN SILICON SUBSTRATE
(BULK MICROMACHINING)



SILICON SUBSTRATE

second prototype

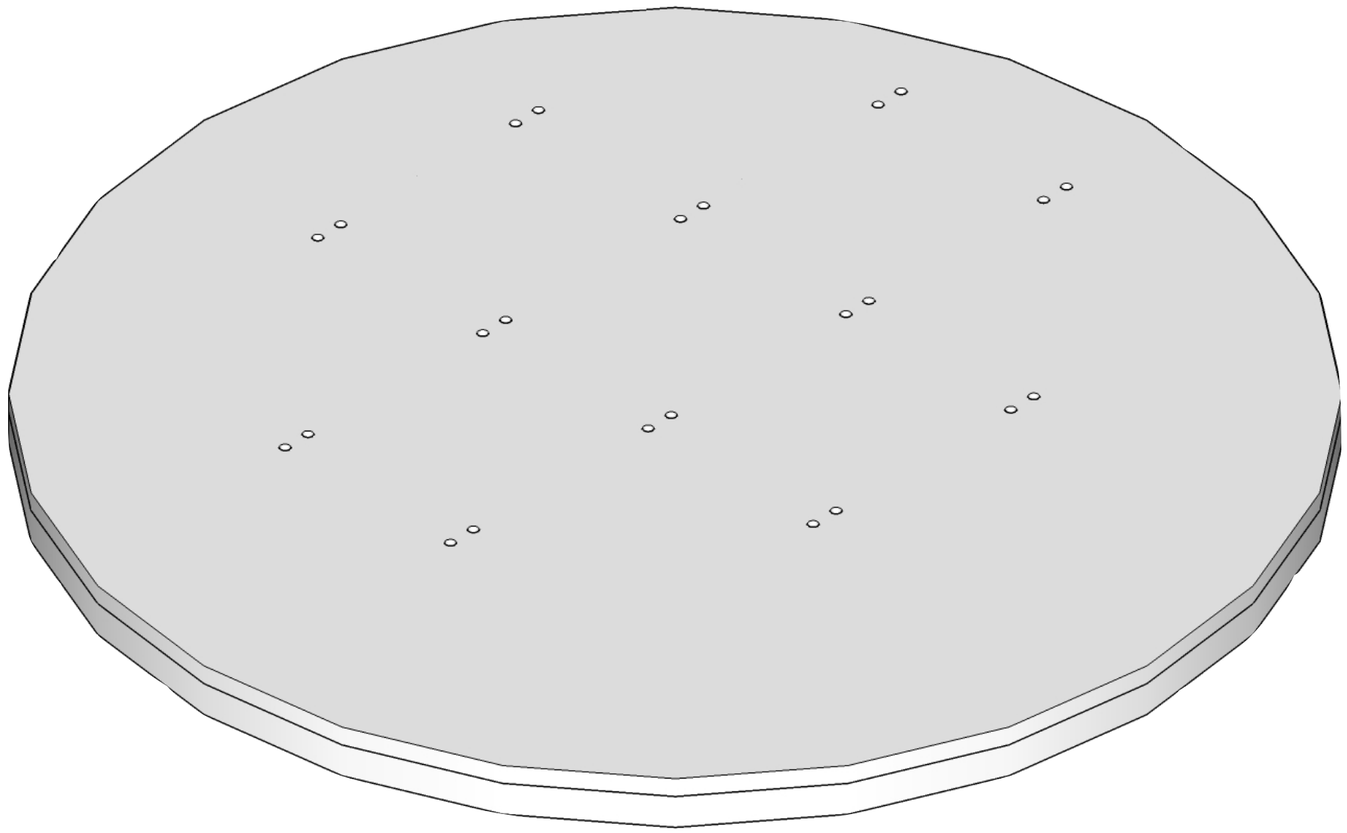
CHANNELS ETCHED IN SILICON SUBSTRATE
(BULK MICROMACHINING)



ETCHING

second prototype

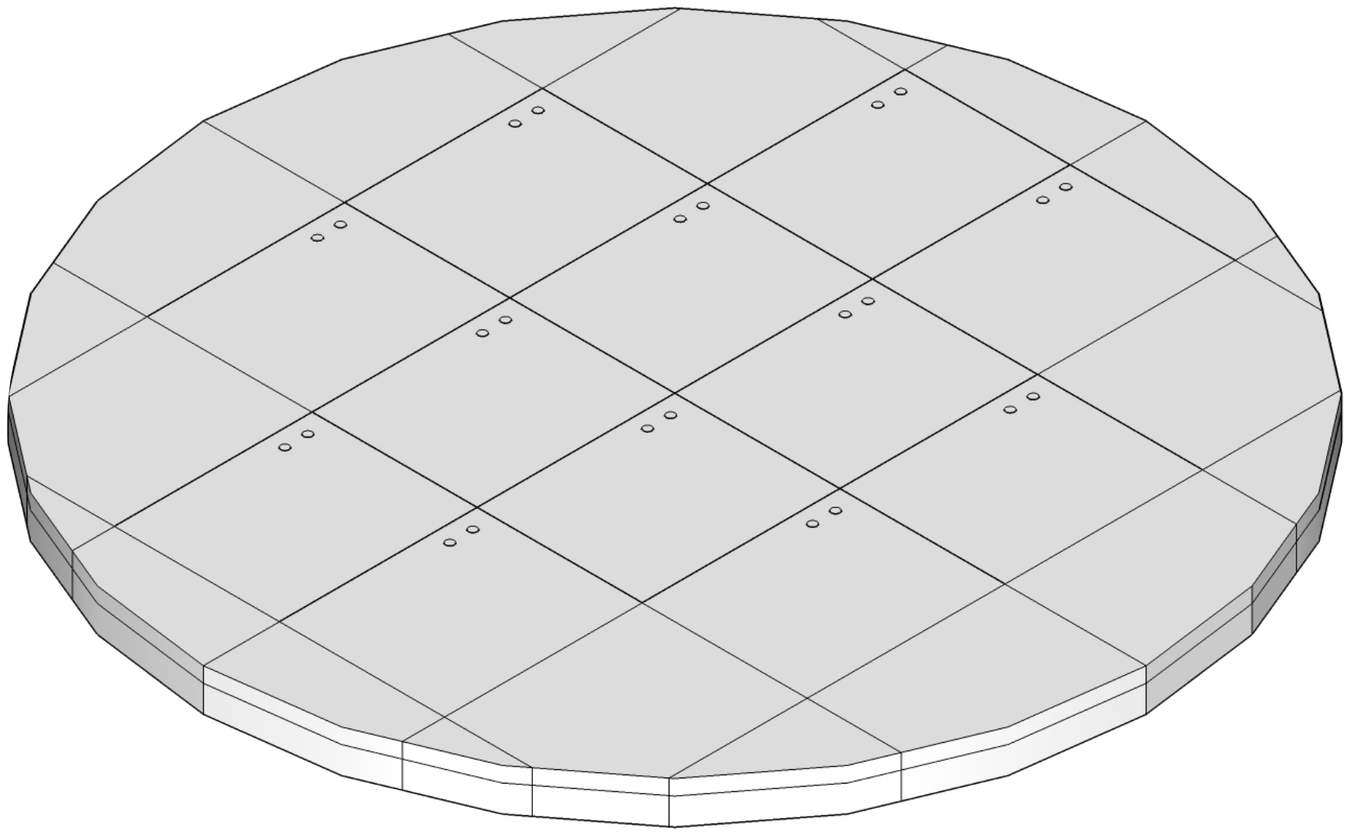
CHANNELS ETCHED IN SILICON SUBSTRATE
(BULK MICROMACHINING)



BONDING OF Si SUBSTRATE WITH THROUGH-HOLES

second prototype

CHANNELS ETCHED IN SILICON SUBSTRATE
(BULK MICROMACHINING)



DICING

second prototype

CHANNELS ETCHED IN SILICON SUBSTRATE
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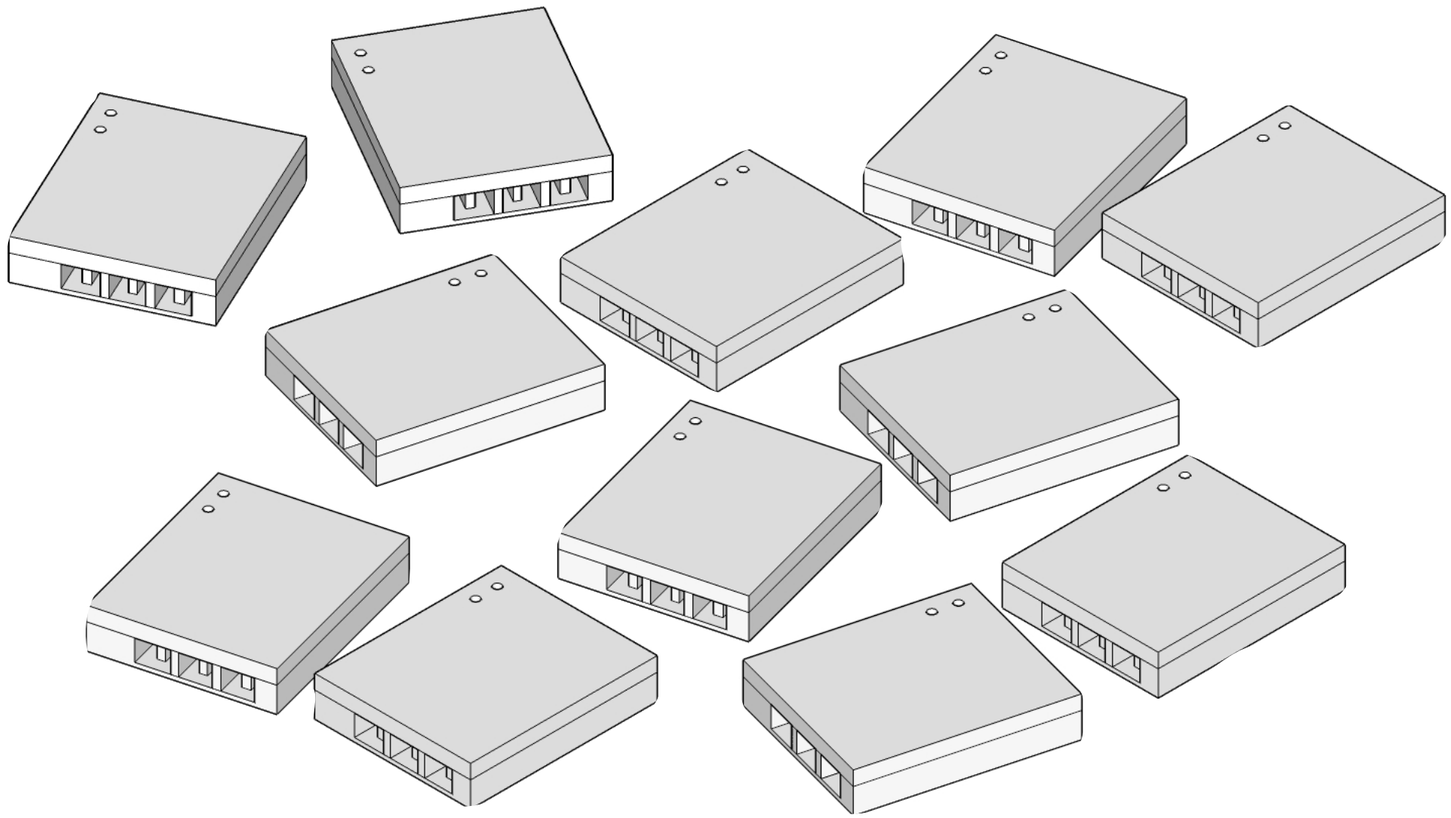

second prototype

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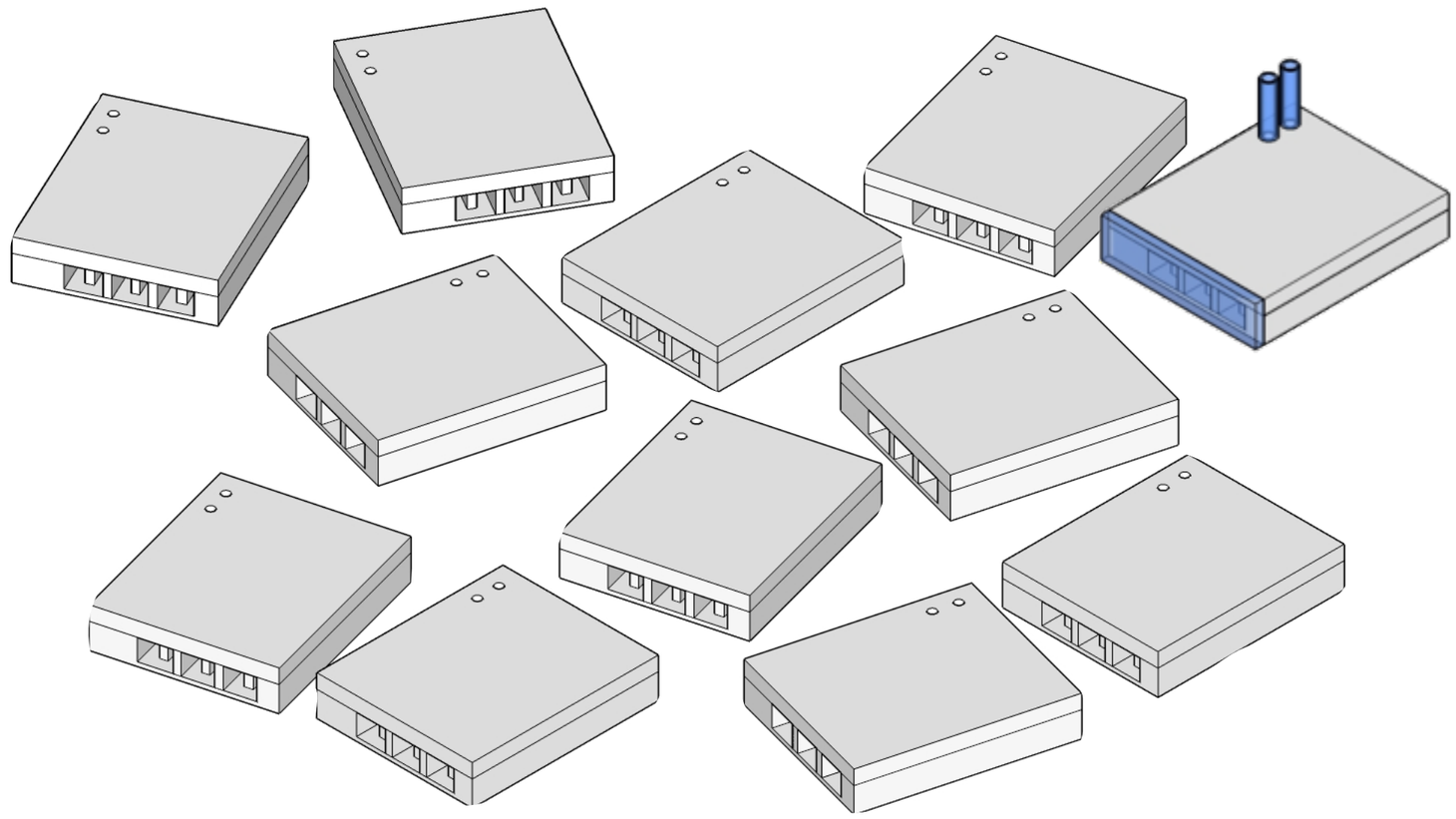
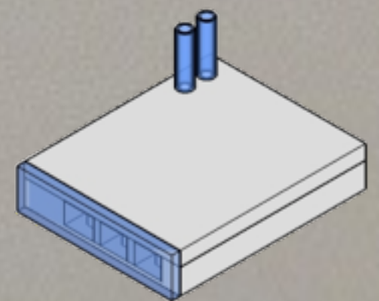


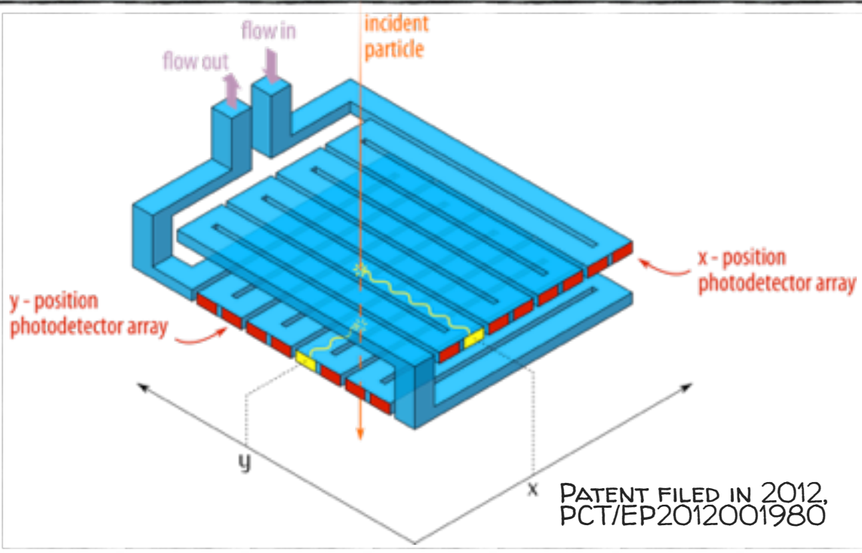
GLUEING OF WINDOW AND TUBES

EXPERIMENTAL CHARACTERISATION WITH PMT

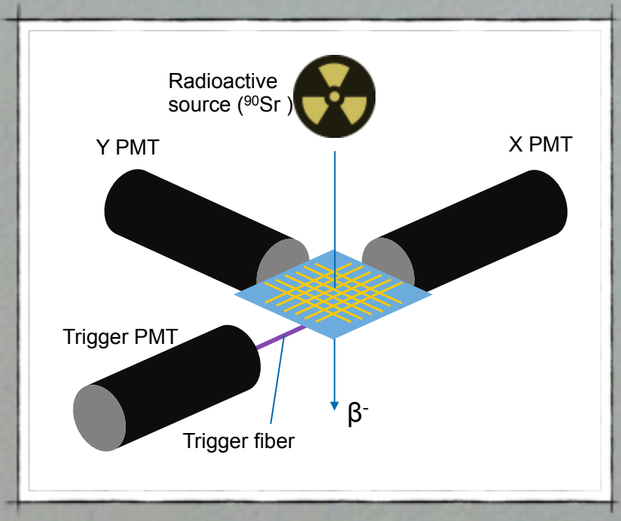
	PLASTICS	MICROSCINT SU-8 AU-COAT	MICROSCINT SILICON AL-COAT
SCINTILLATOR	0.5 MM	0.2 MM	0.18 MM
LIGHT YIELD	4.4 PE 9 PE/MM	1.6 PE 8 PE/MM	1.4 PE 7.8 PE/MM

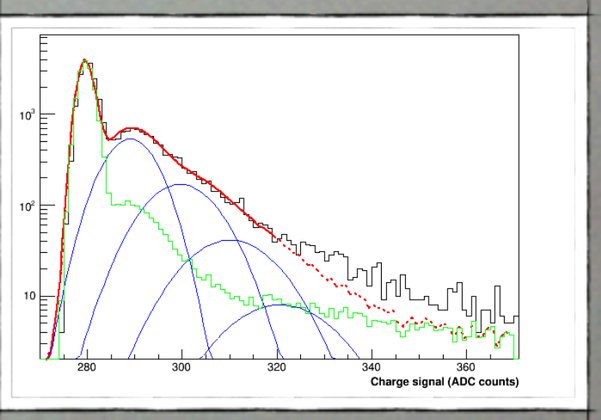


DOUBLE LAYER DEVICES FOR XY RECONSTRUCTION

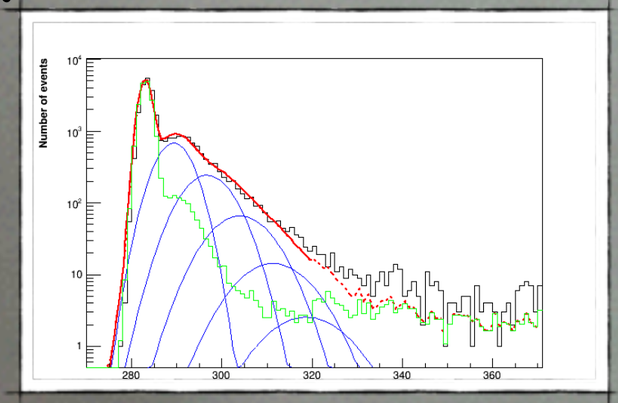


PATENT FILED IN 2012, PCT/EP2012001980





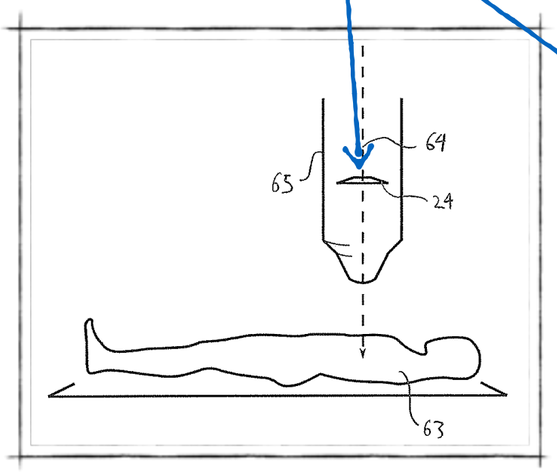
X LAYER 150 μM
0.9 PE
6 PE/MM

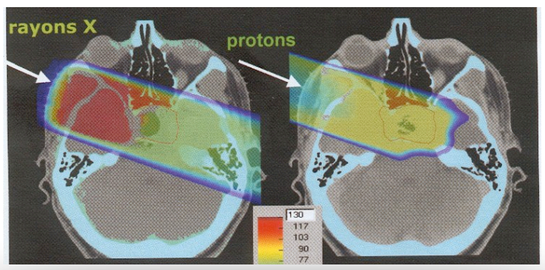


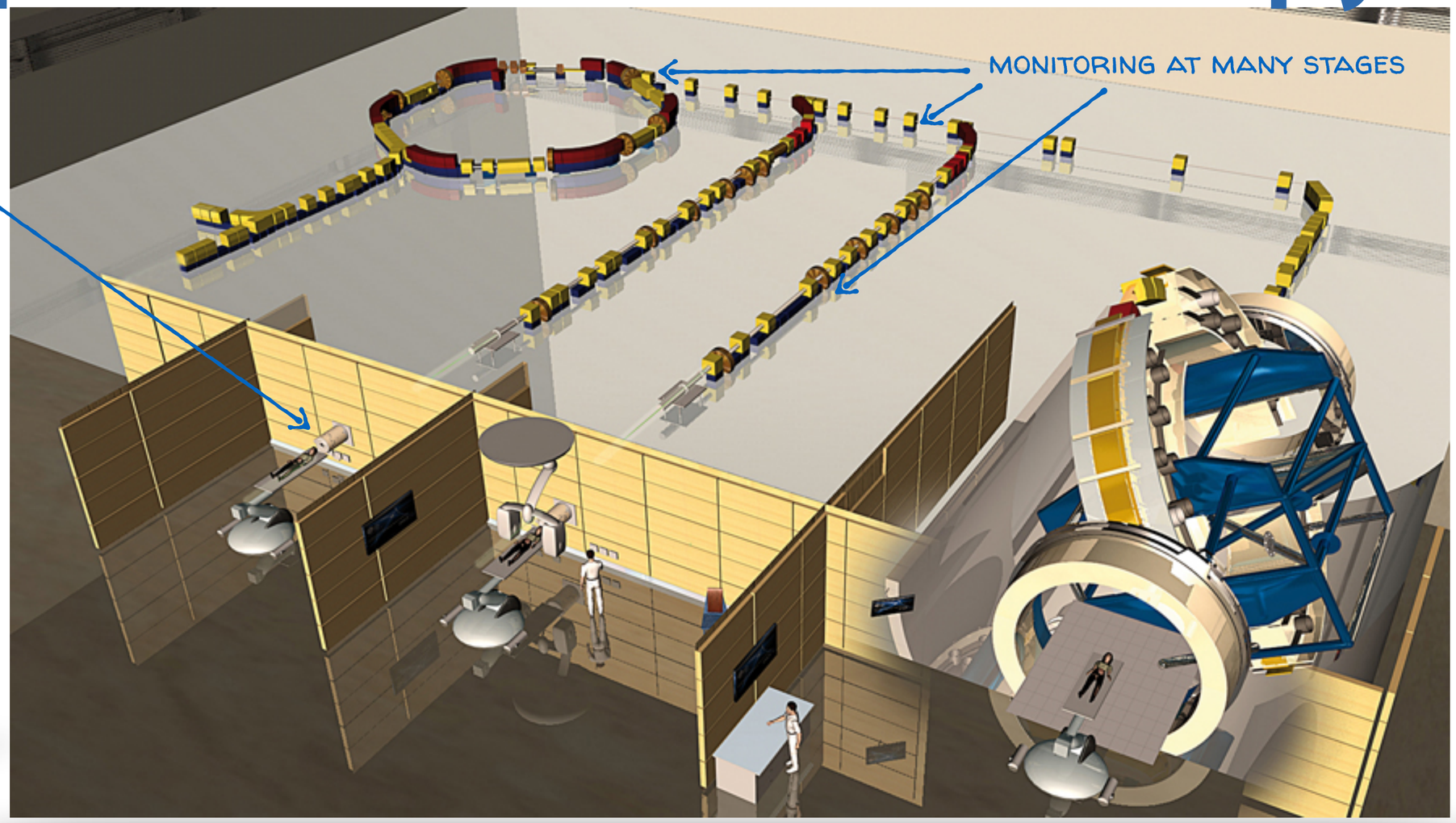
X LAYER 150 μM
1.0 PE
6.7 PE/MM

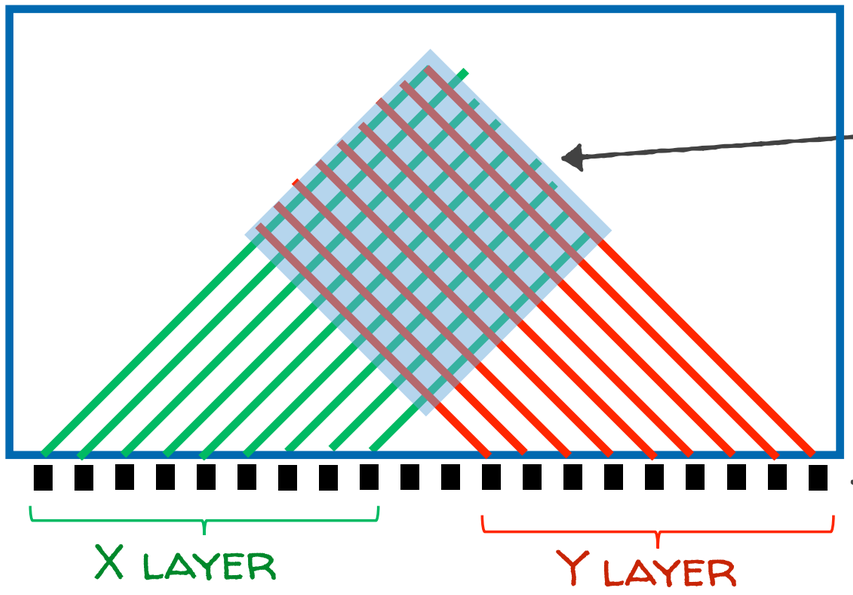
beam profiler for hadrontherapy

THIN MICROFLUIDIC MONITOR

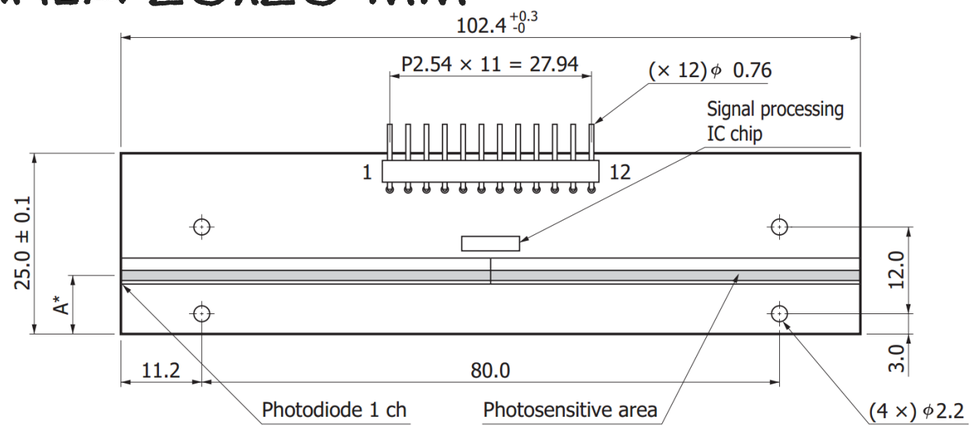








ALL SILICON DEVICE
500 μM THICK (~0.5%X_0)
ACTIVE AREA 20X20 MM^2

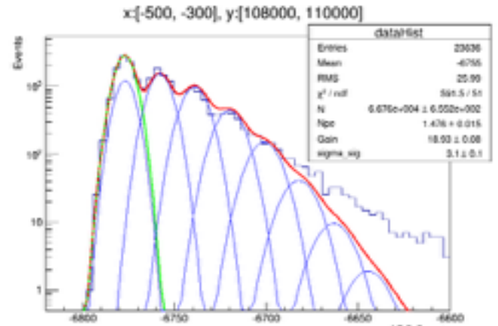


PHOTODIODE ARRAY
HAMAMATSU S8866-128-02

coming up!

Beam test at PSI to validate XY device read-out by photodiodes as beam monitor for hadrontherapy

SiPM readout of single layer at CERN (with Christian Joram)



Implement SiPM readout at CERN (INFN)

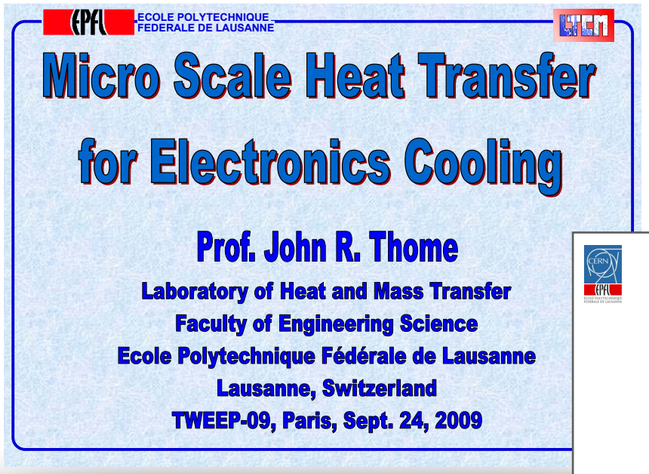
Integrate aSi photodiodes on microfluidic devices (EPFL-PVLAB)

Large area detectors (with Rui de Oliveira)

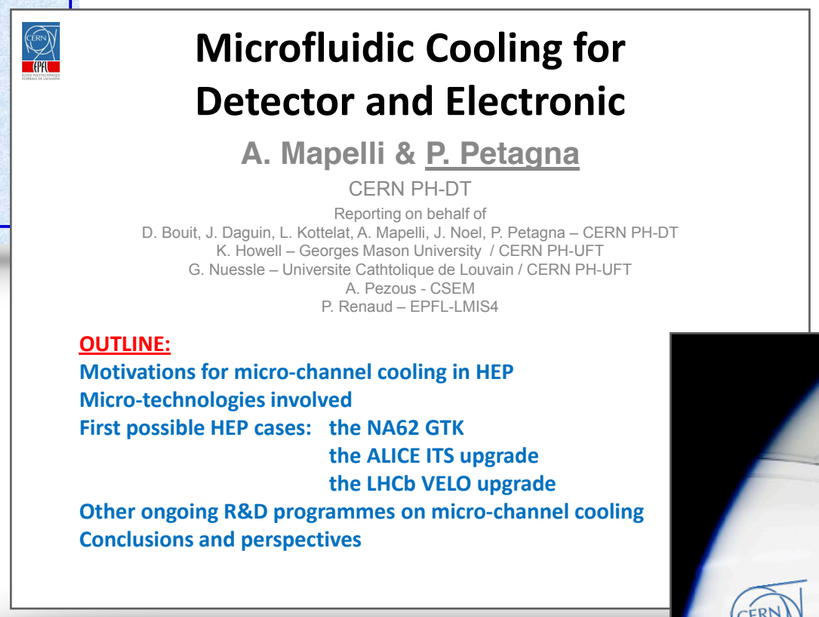
MicroCool

Microfabricated on-detector cooling systems

microCool at TWEPP



2009


Microfluidic Cooling for Detector and Electronic

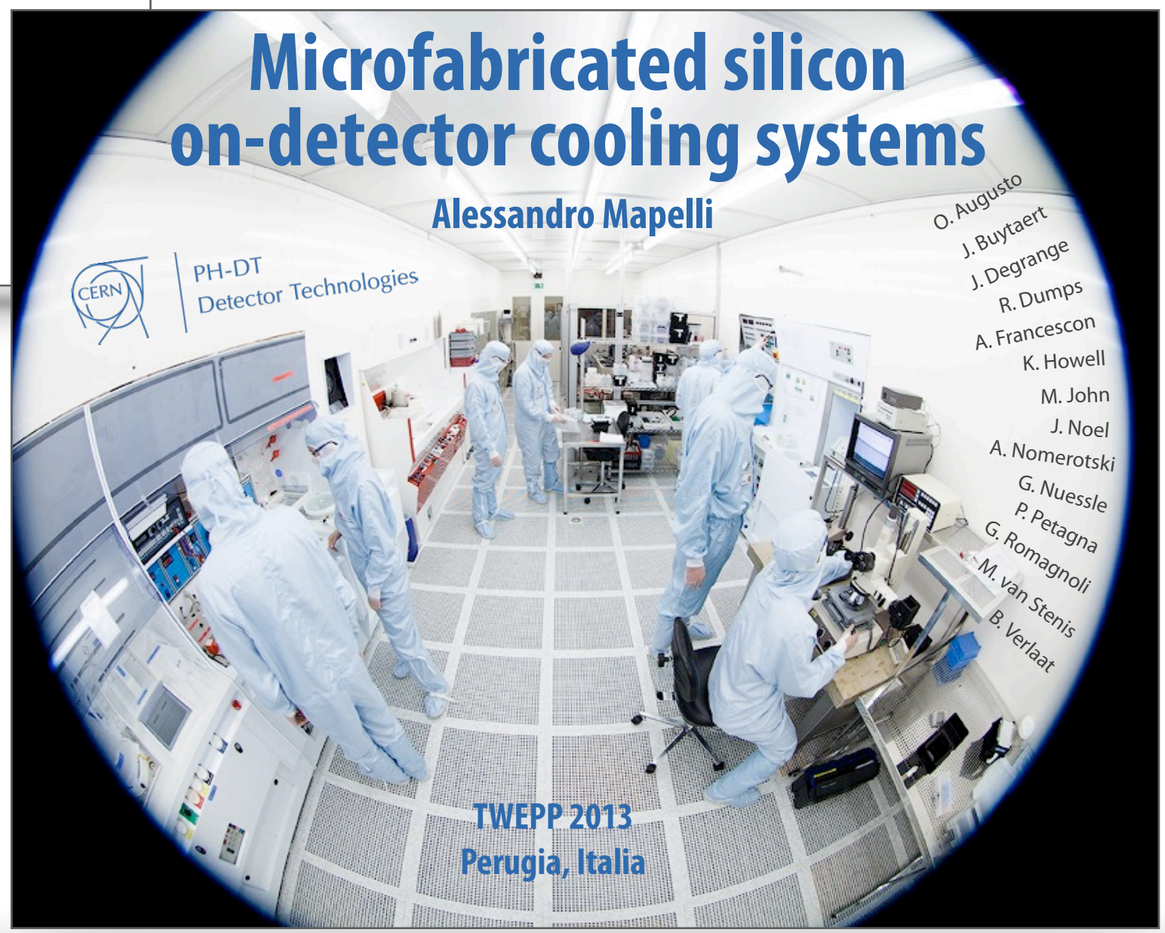
A. Mapelli & P. Petagna

CERN PH-DT

Reporting on behalf of
D. Bouit, J. Daguin, L. Kottelat, A. Mapelli, J. Noel, P. Petagna – CERN PH-DT
K. Howell – Georges Mason University / CERN PH-UFT
G. Nuessle – Universite Cathtolique de Louvain / CERN PH-UFT
A. Pezous - CSEM
P. Renaud – EPFL-LMIS4

OUTLINE:
Motivations for micro-channel cooling in HEP
Micro-technologies involved
First possible HEP cases: the NA62 GTK
the ALICE ITS upgrade
the LHCb VELO upgrade
Other ongoing R&D programmes on micro-channel cooling
Conclusions and perspectives

2011



2013

Motivation

Issues to be addressed when designing on-detector cooling systems

1. Minimization of material budget
2. Efficient thermal management
3. Minimization of ΔT between heat source and heat sink

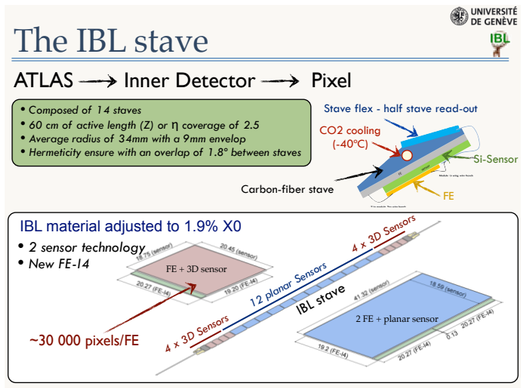
Integration of cooling and detector lay-out

The cooling has to be considered as an integral part of the detector and the experiment, therefore physicists and engineers shall collaborate from the beginning of the conceptual design of the systems, with an overall view on all subparts.

Engineering Cooling Forum
30 October 2008, CERN

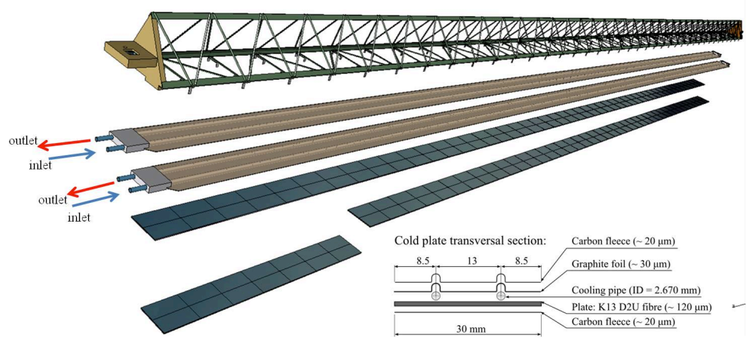
Integrating Cooling in Support Structures.. ..or Somewhere in the Silicon?

ATLAS IBL

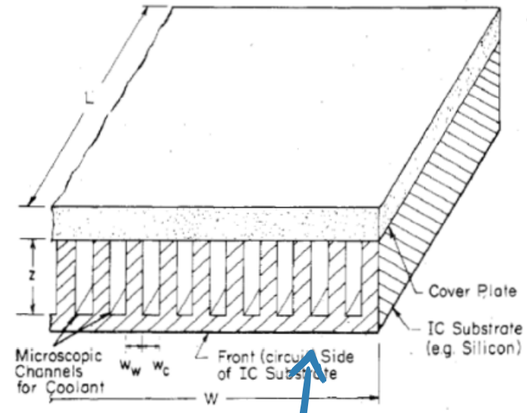


from J. Bilbao http://indico.cern.ch/sessionDisplay.py?sessionId=6&confId=208719#20130125

ALICE ITS Upgrade

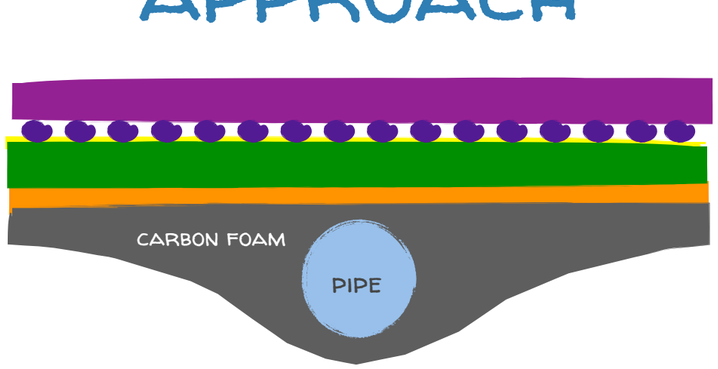


ALICE ITS Upgrade Outer Barrel Stave



D.B. Tuckerman and R.F.W. Pease. IEEE Elec. Dev. Letters, Vol. 2. 5. 1981

IN-MECHANICS APPROACH



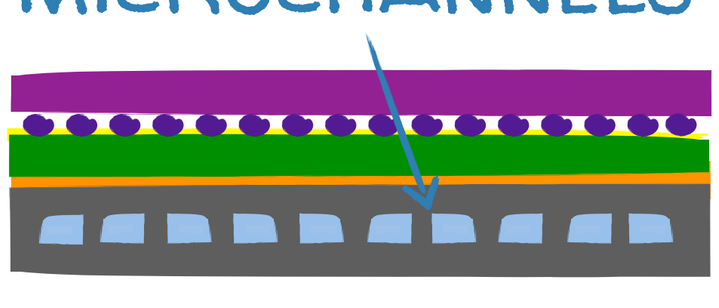
Si DETECTOR

BUMP BONDS

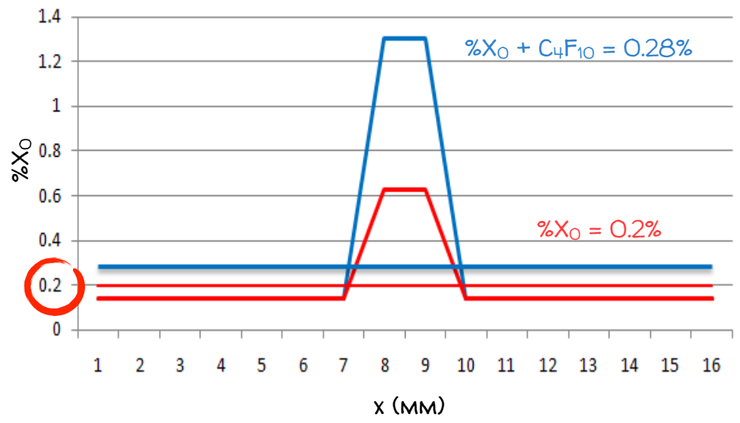
READ-OUT CHIPS

THERMAL INTERFACE

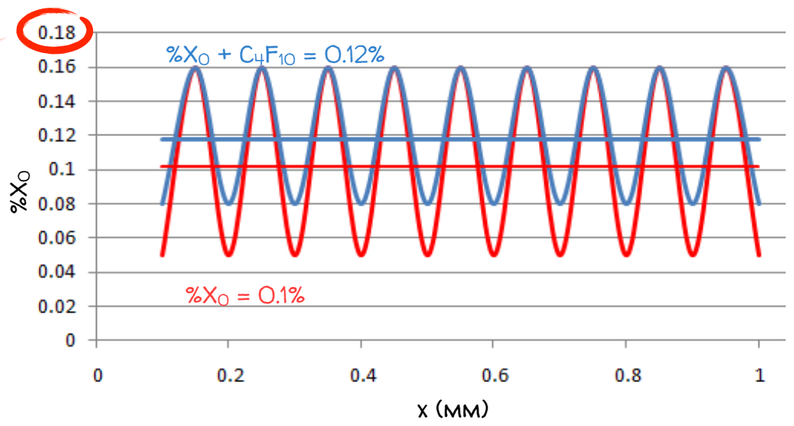
SILICON COOLING MICROCHANNELS



NO CTE MISMATCH



X_0 calculations by Claudio Bortolin



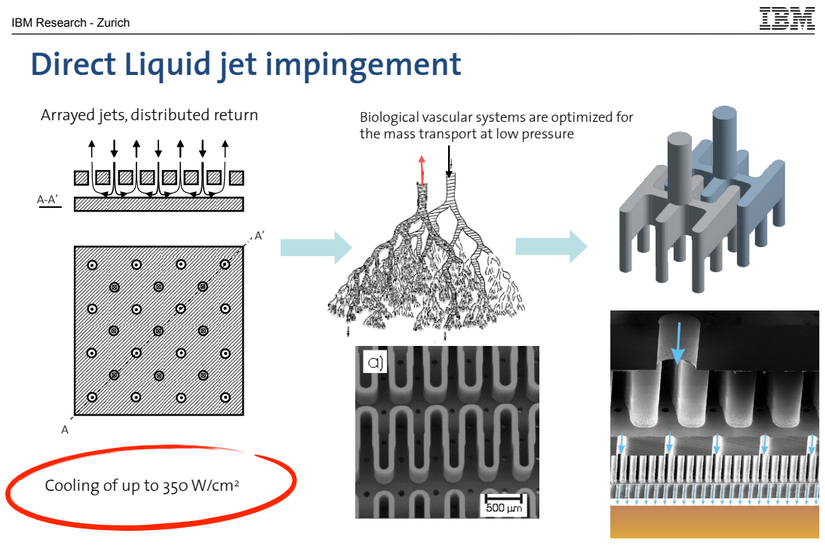
10°C

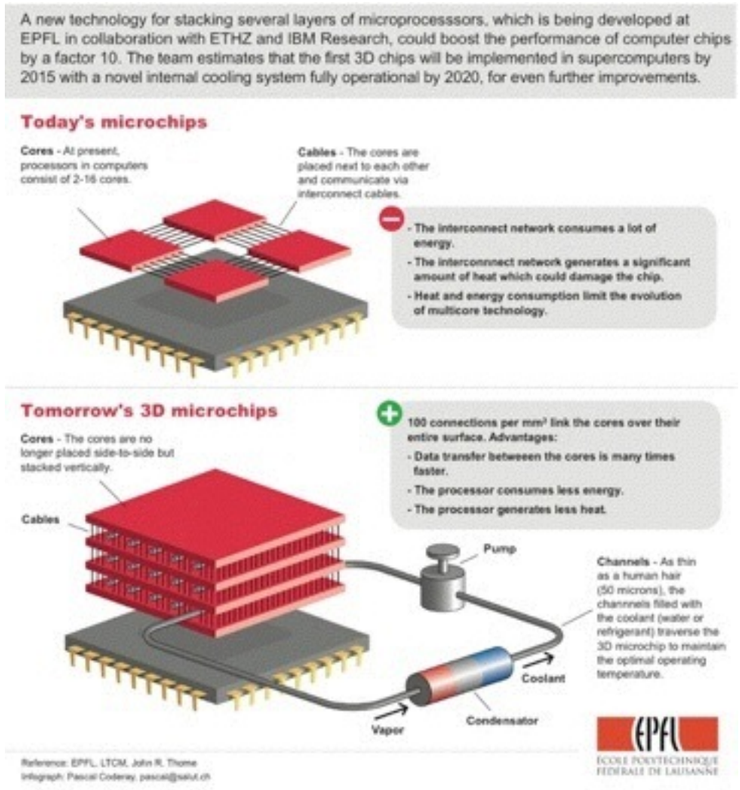
ΔT between heat source and heat sink for power dissipations of ~1W/cm² (currently installed systems ~15°C)

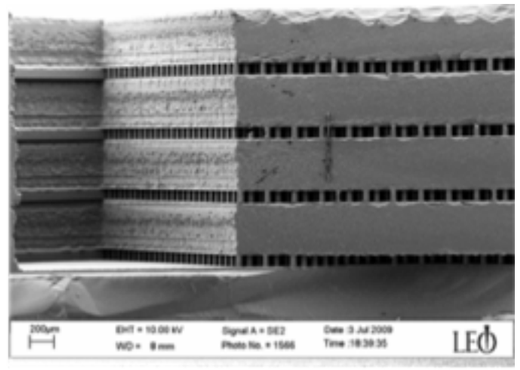
5°C

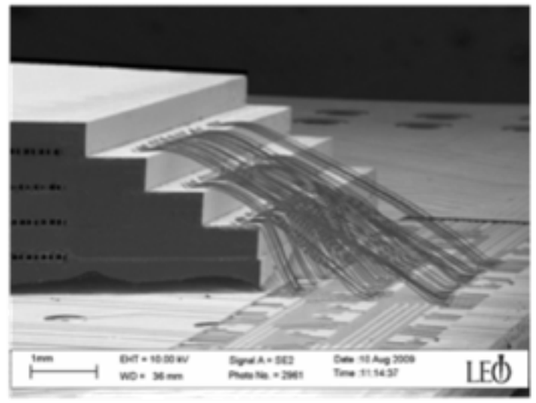
Silicon Microfluidic Cooling

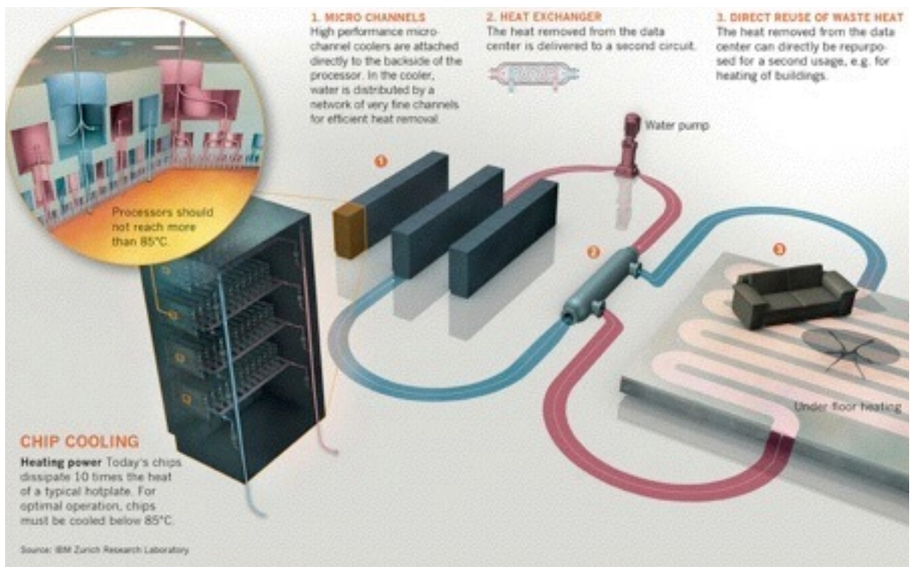
OUT OF THE HEP WORLD



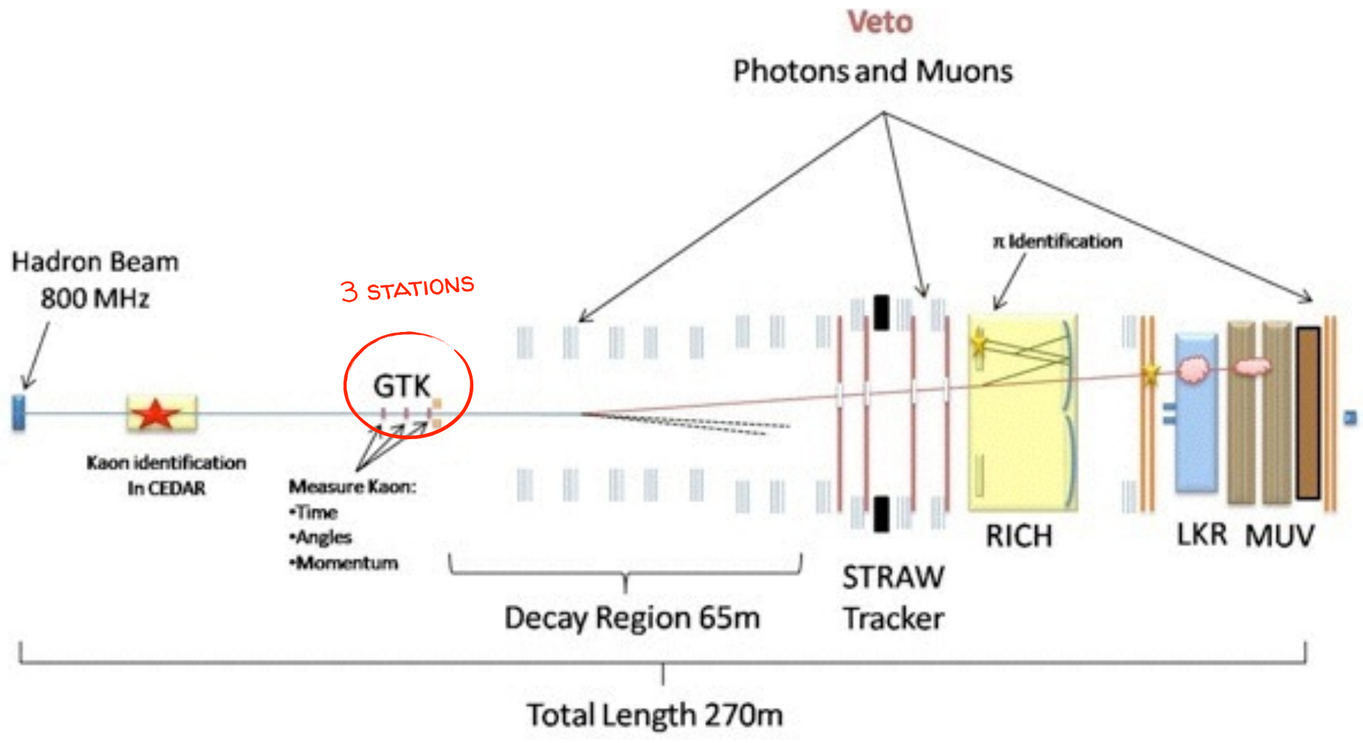


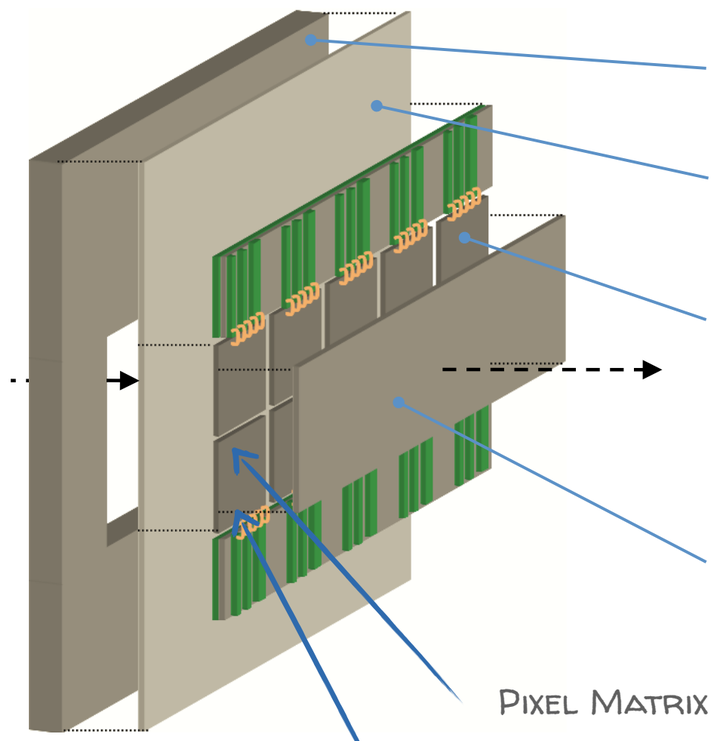






NA62-GTK





support and alignement structure

Cooling plate

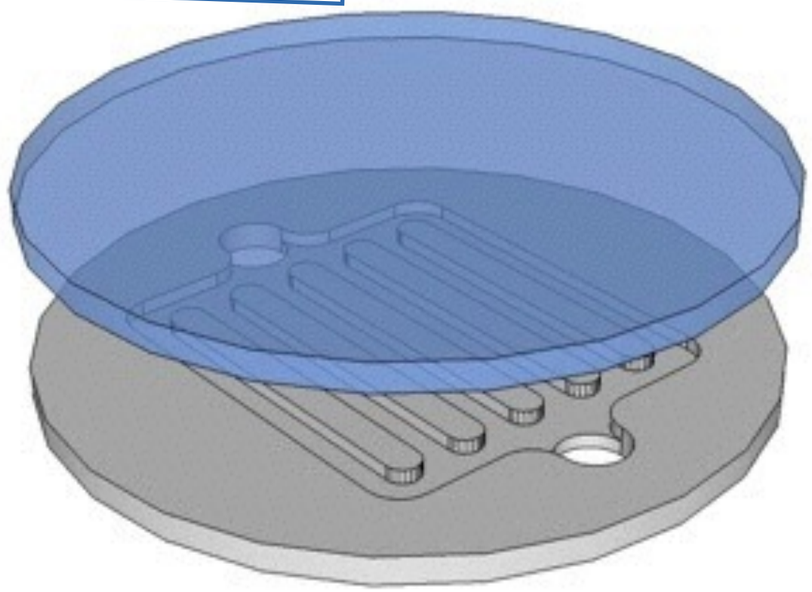
Readout chip
(12 x 20 mm), heat production
ca. 3.2W per chip (2 W/cm^2)

Sensor, silicon pixels
(30 x 60 mm)

Pixel Matrix 0.4 W/cm^2

EoC 2.5 W/cm^2

150 µm thick Silicon substrate with microchannels

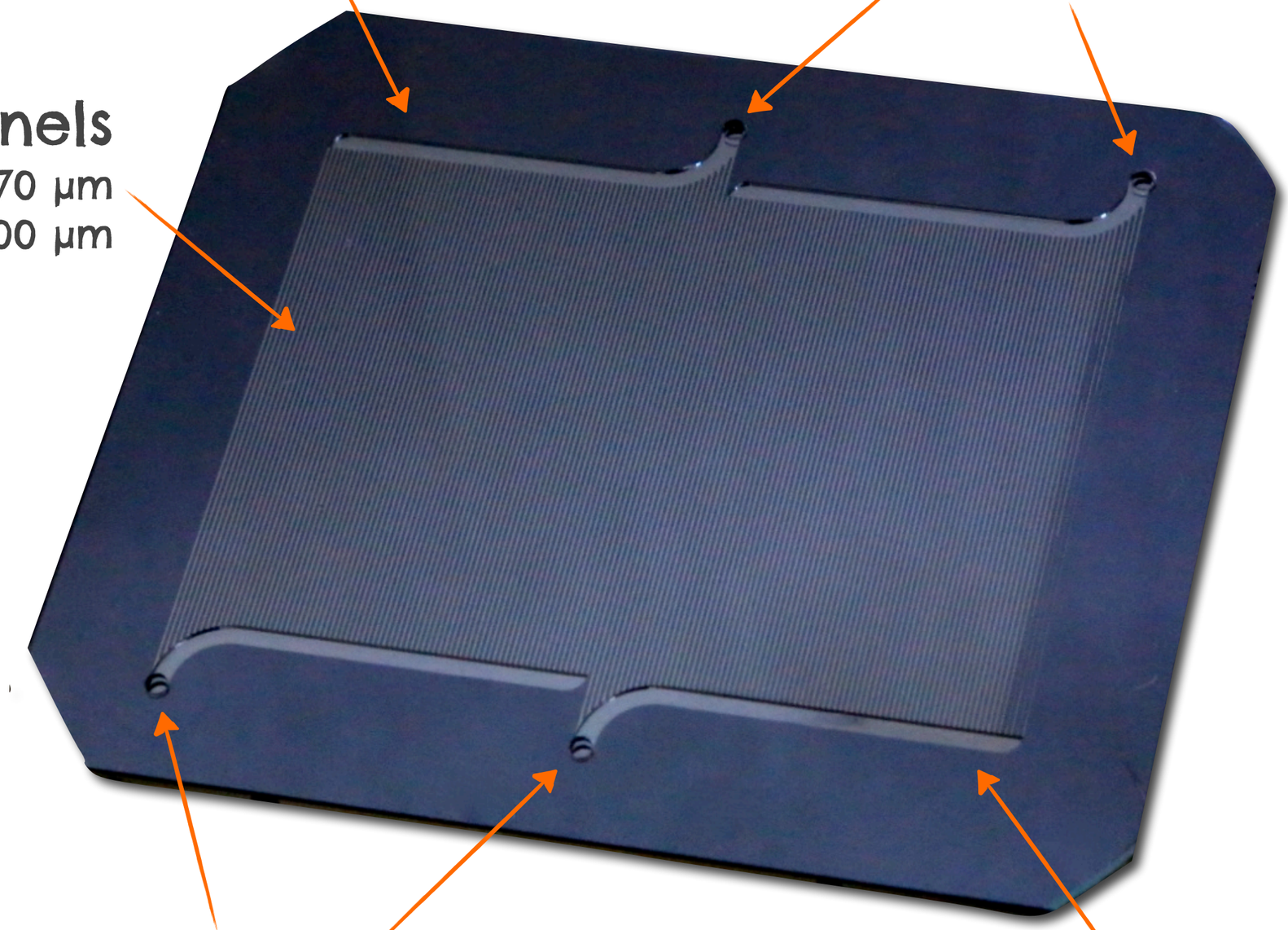


Silicon Cooling Plate

distribution manifolds
280 µm deep

fluidic inlets
1.6 mm

150 microchannels
200 x 70 µm
pitch 400 µm



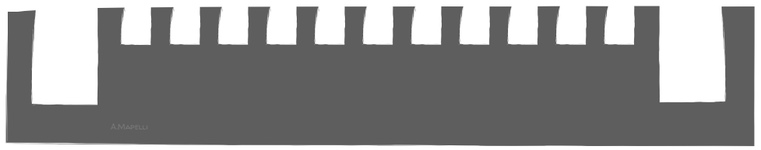
fluidic outlets
1.6 mm

recollection manifolds
280 µm deep

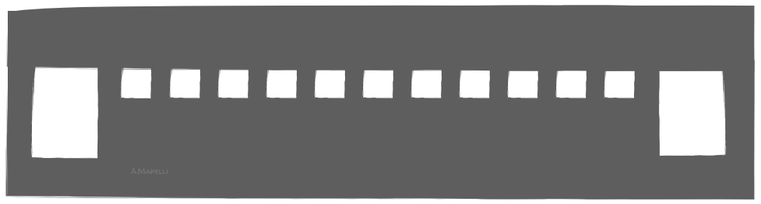
Microfabrication

Prototypes fabricated at EPFL by PH-DT.
Six pre-production modules outsourced to IceMOS.

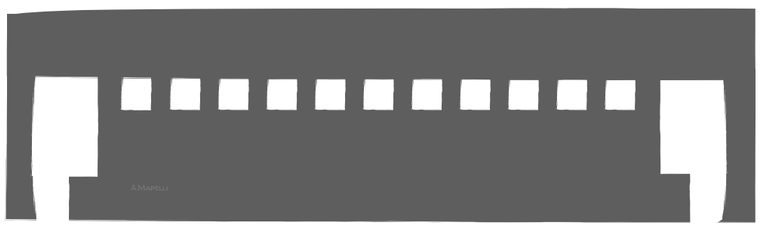
Si wafer



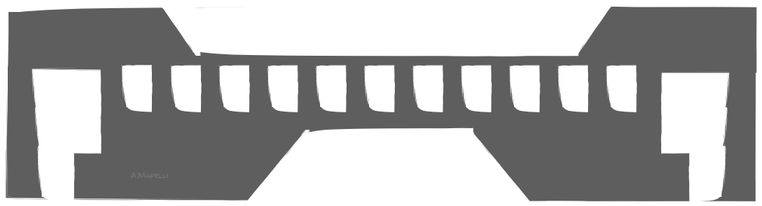
Plasma etching of channels & manifolds



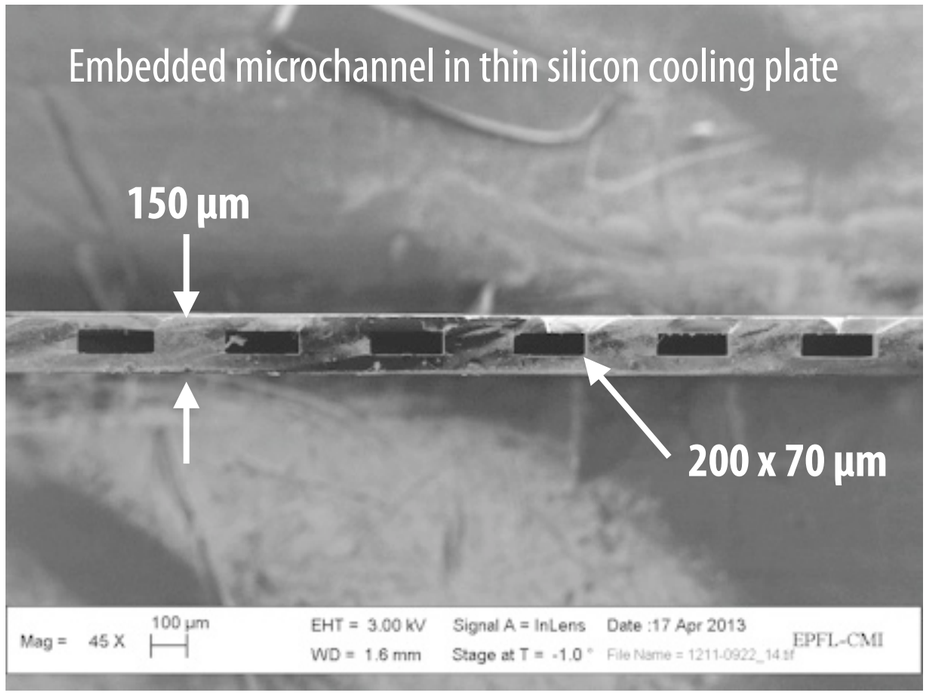
Bonding of Si cover

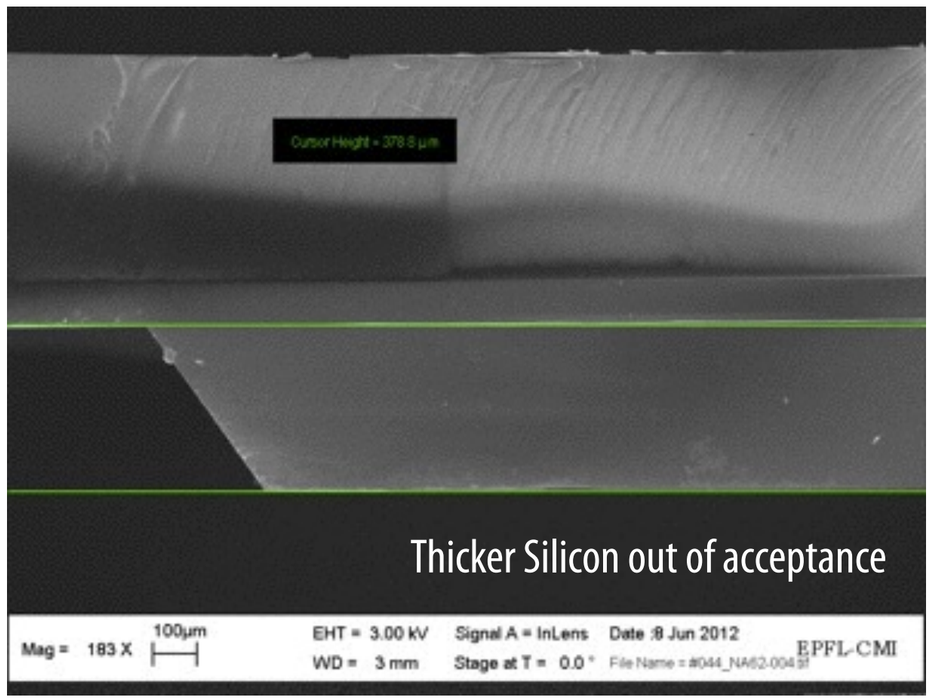


Plasma etching of fluidic openings



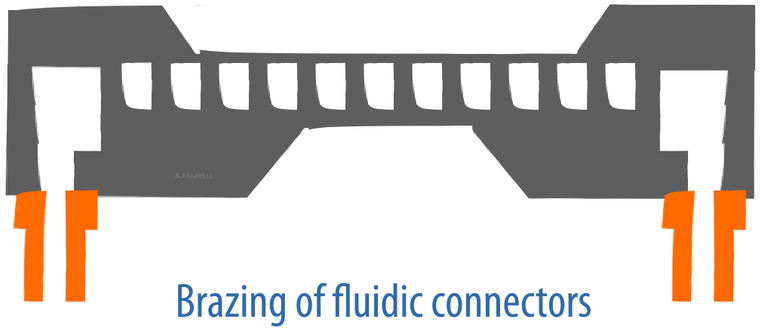
Wet etching of acceptance



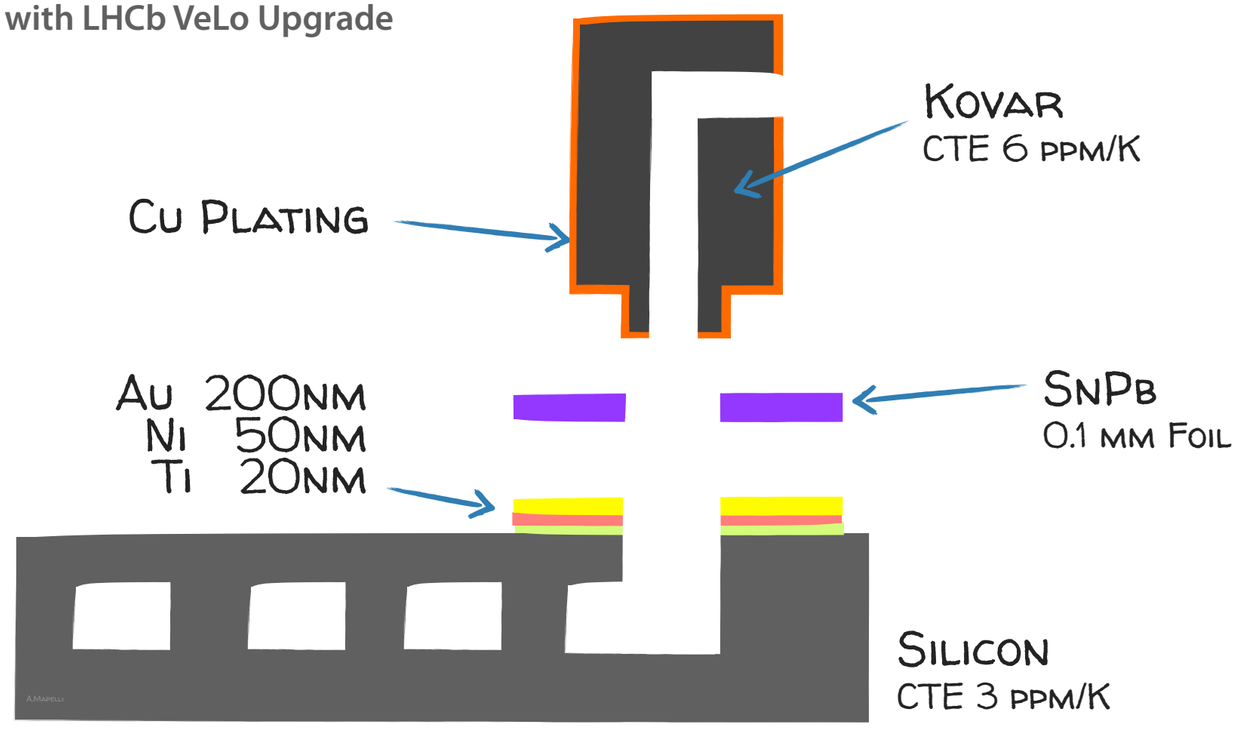


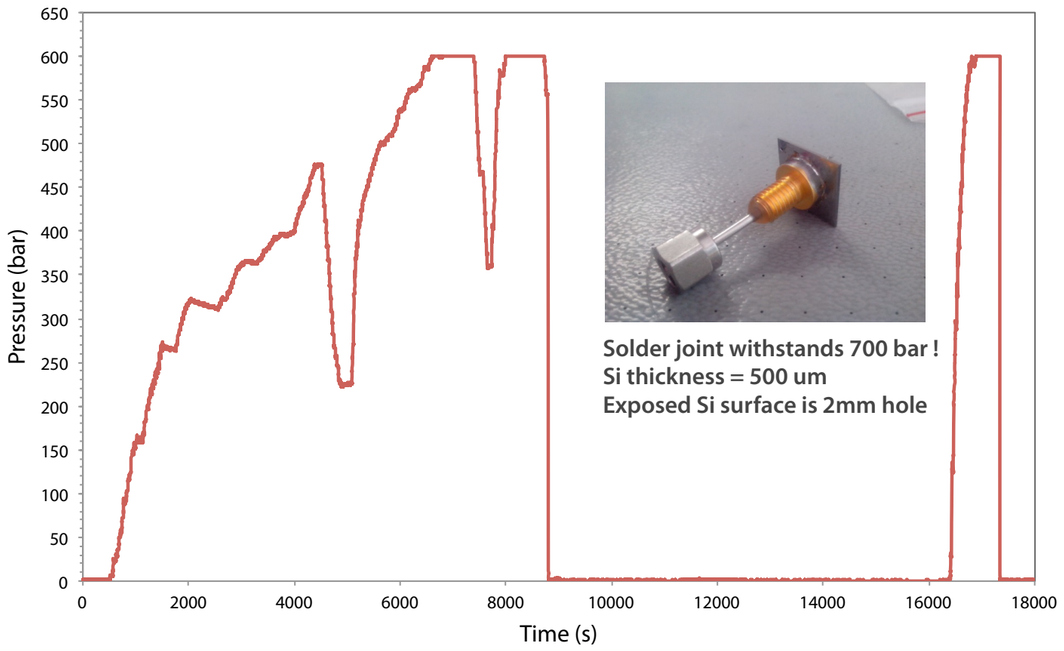
Fluidic Connectors

Common development with LHCb VeLo Upgrade

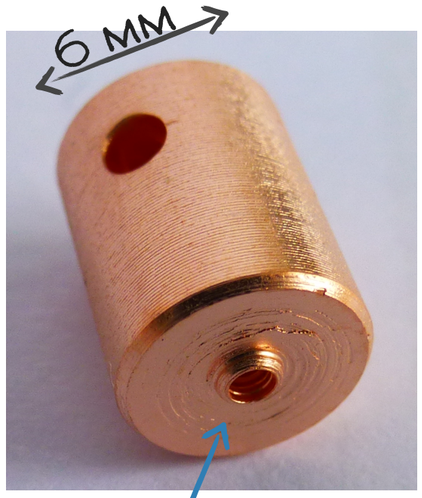


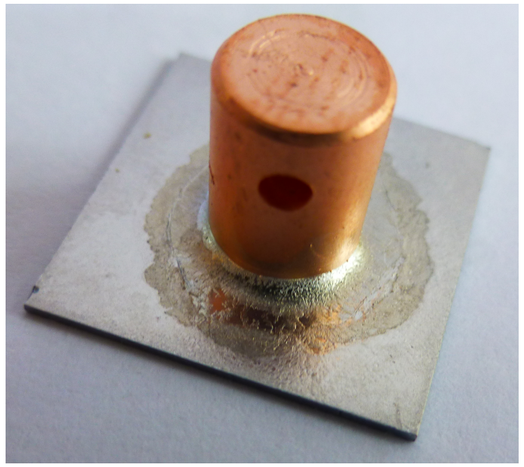
Brazing of fluidic connectors





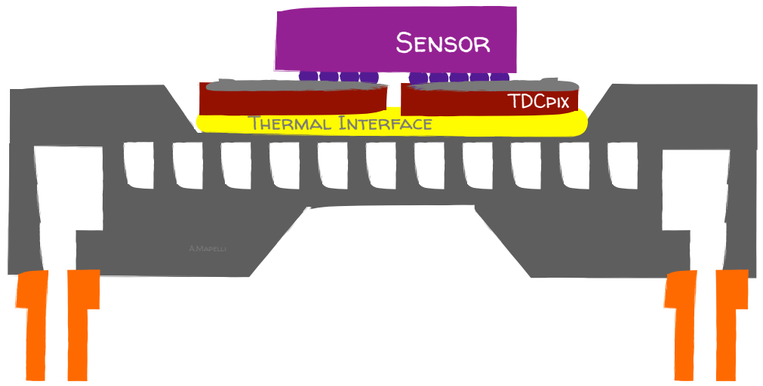
Limitation of the test set-up read-out at 600 bars
Limitation of the pump **700 bars**
No failure of the soder joint

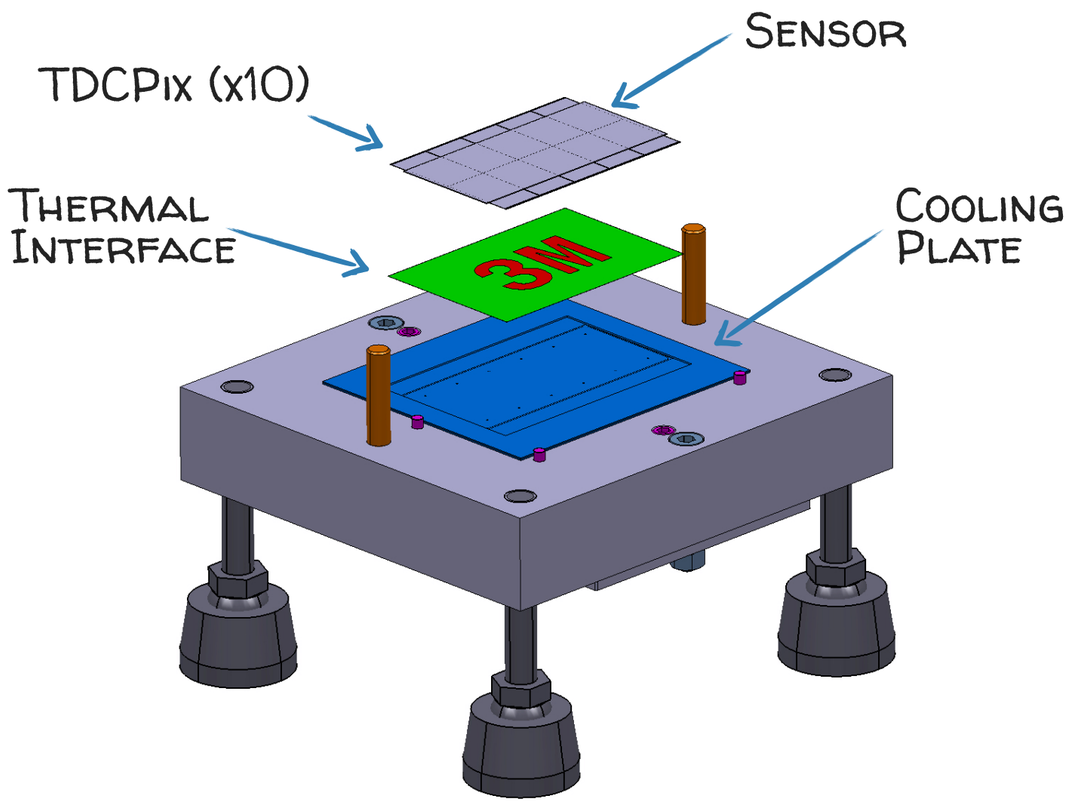


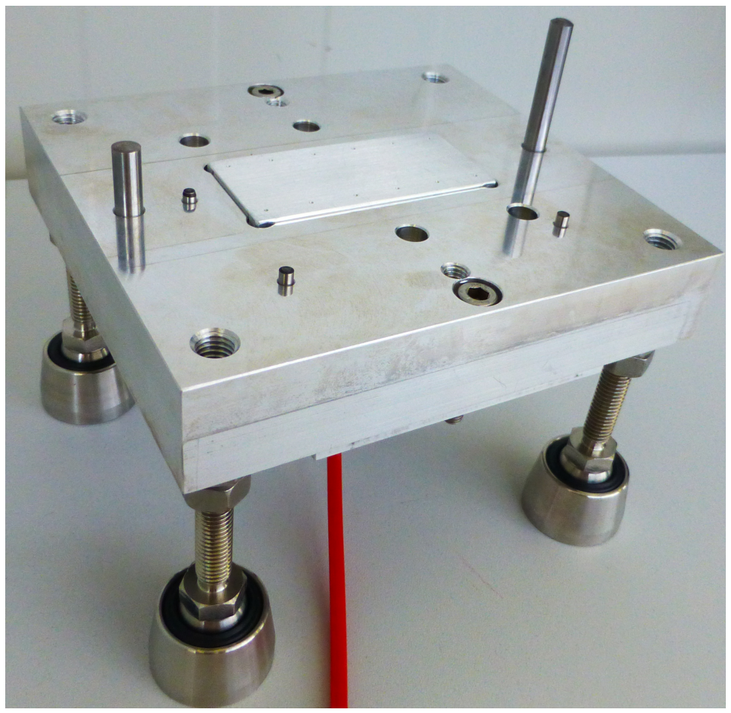


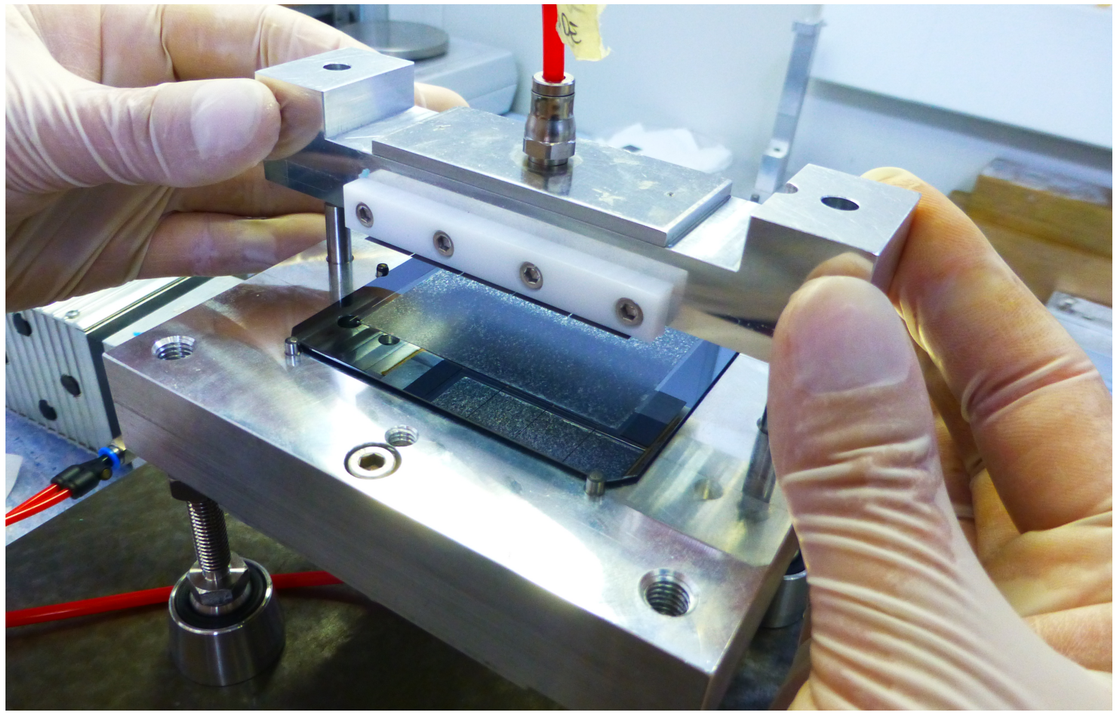
preliminary prototypes
size reduction and different geometries under study

Assembly to Sensor/TDCPix







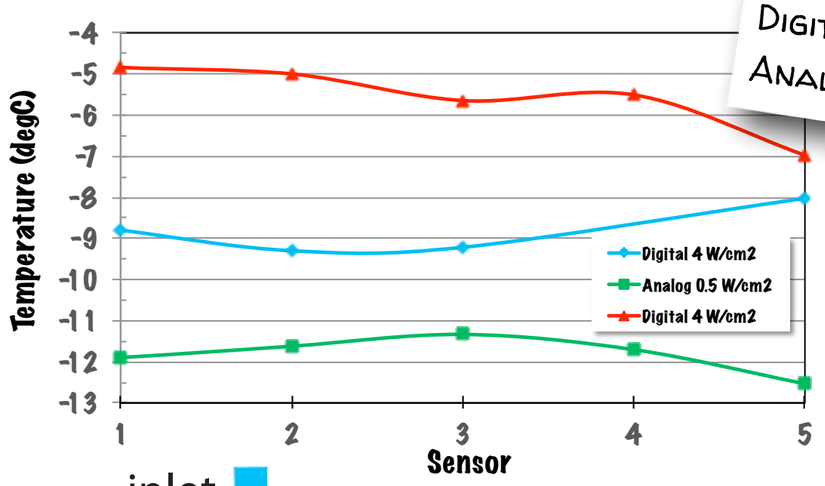


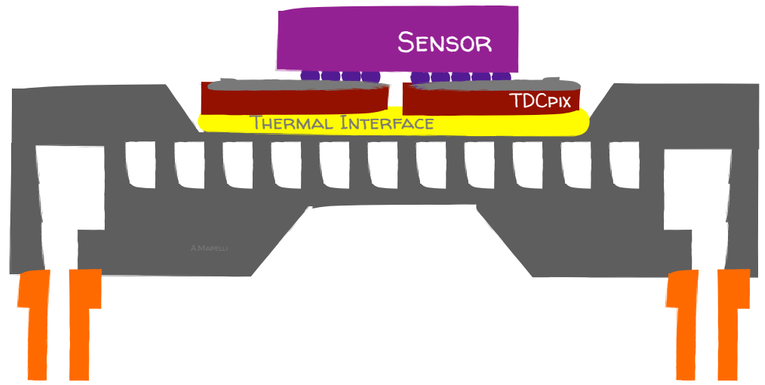
Experimental Validation

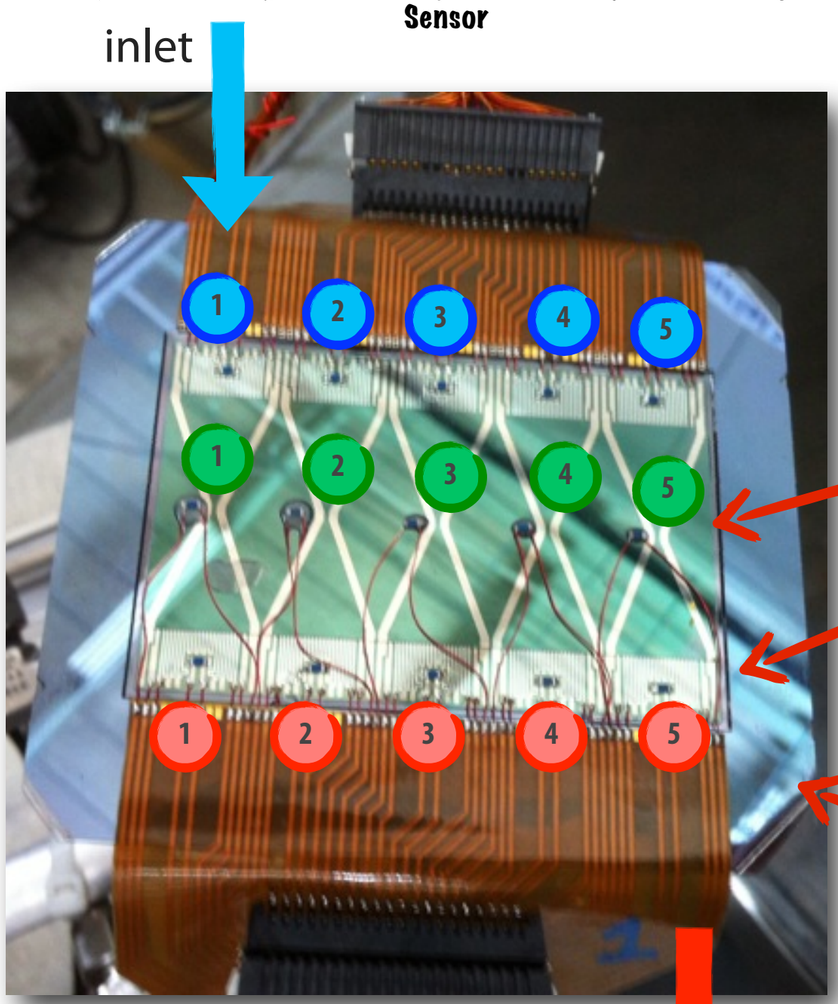
Liquid Cooling C_6F_{14}

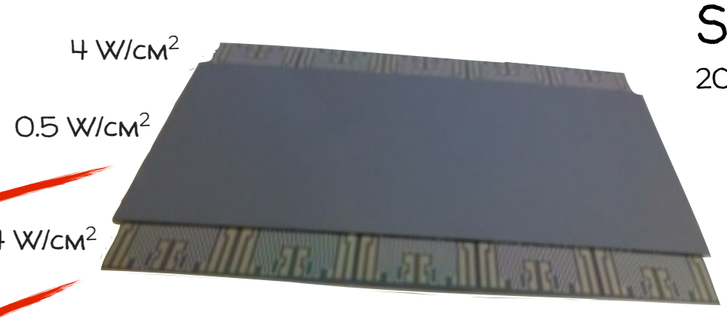
Nominal Power Dissipation 24 W
Results presented for extreme scenario 48 W

C_6F_{14}: 7g/s, −19°C at inlet
Digital Power 38 W
Analog Power 10 W







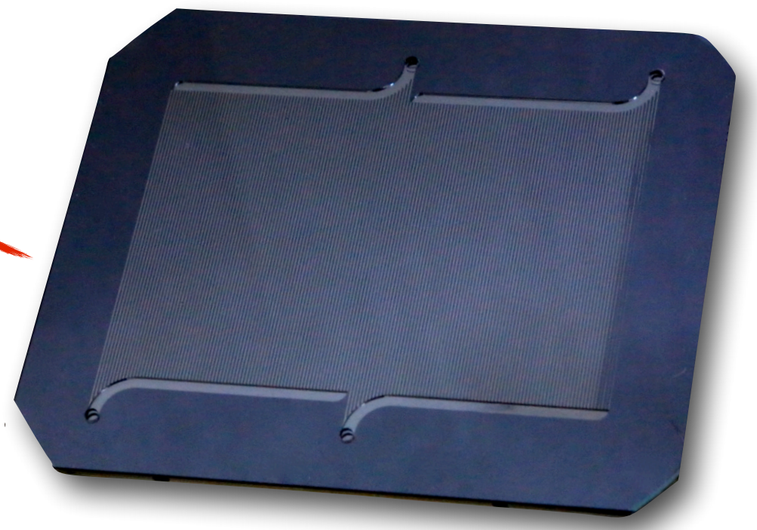


Sensor Dummy

200 µm thick Si

TDCPix Dummies

100 µm thick Si
20 metal lines to simulate power dissipation of analog and digital parts of 10 TDCPix chips

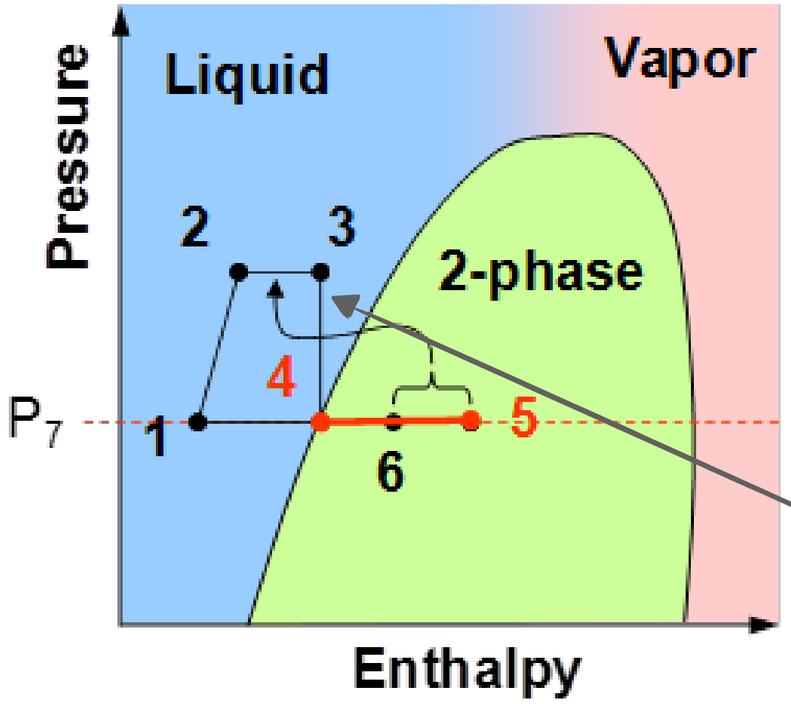


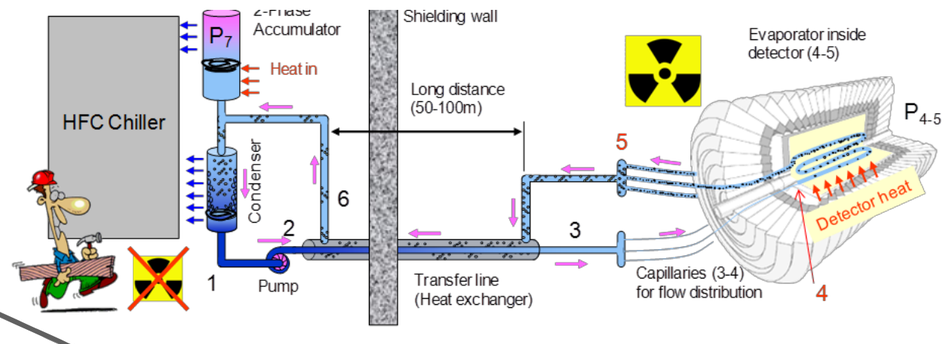
Cooling Plate

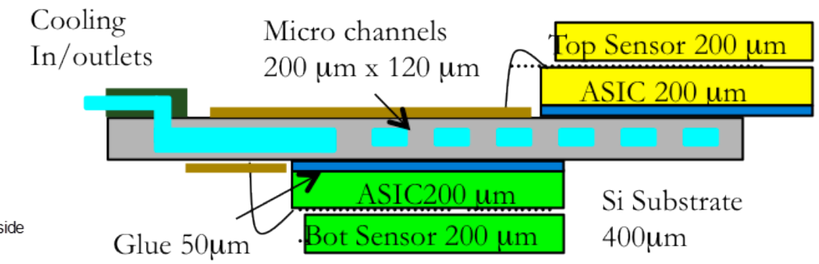
150 µm thick Si

LHCb VeLo Upgrade

Evaporative CO_2 in silicon microchannels



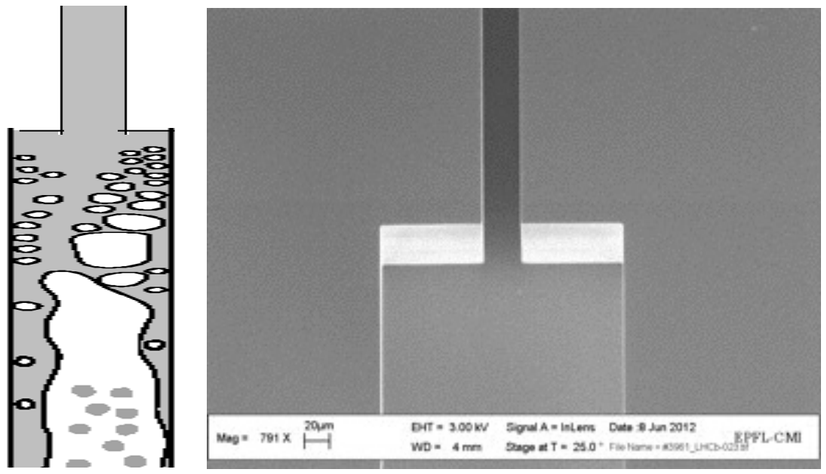




Inlet restrictions
30 x 60 µm

Liquid

2-phase



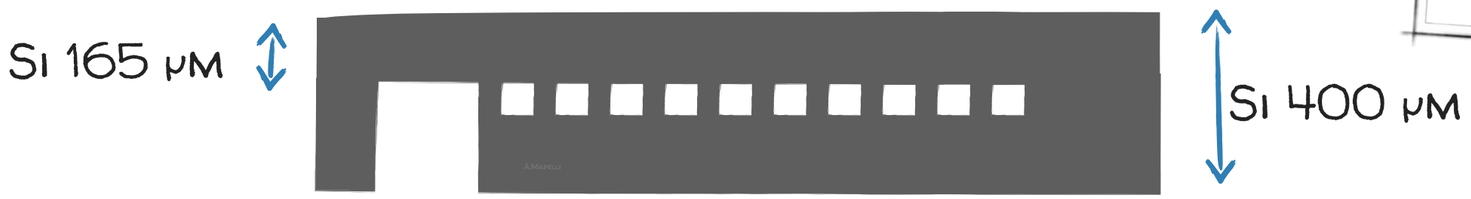
Transition from inlet restrictions
to evaporative microchannels

Microchannels
200 x 60 µm

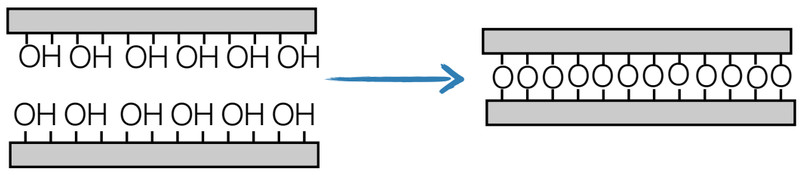
pressure resistance

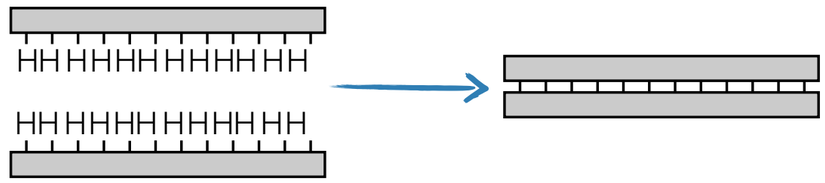
1. operating pressure at low temperature ~15 bar
2. pressure at room temperature start-up ~ 60 bar
3. validation pressure with safety factor ~150 bar

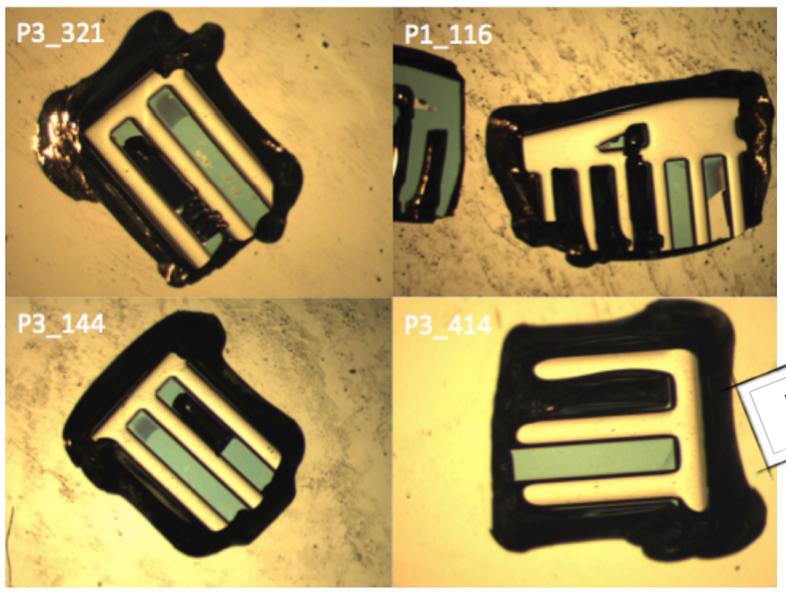
Samples produced by LETI-3S



Hydrophilic Bonding vs. Hydrophobic Bonding

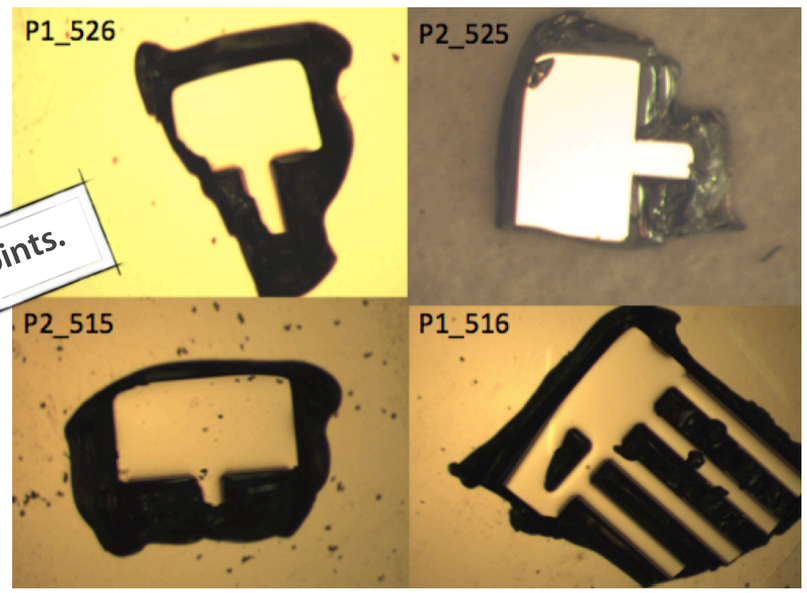






Round 1

Manifolds are the weak points.



Delamination + Si Rupture

Rupture at 400 bars due to delamination

Round 2

with improved connector over manifolds (R. Dumps)

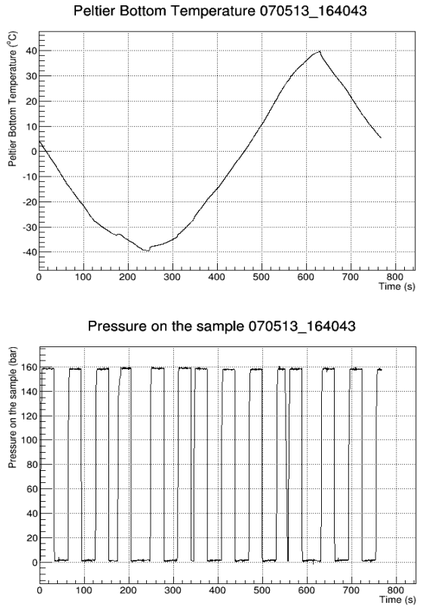
No Delamination

Hold 700 bars

Limitation of pump

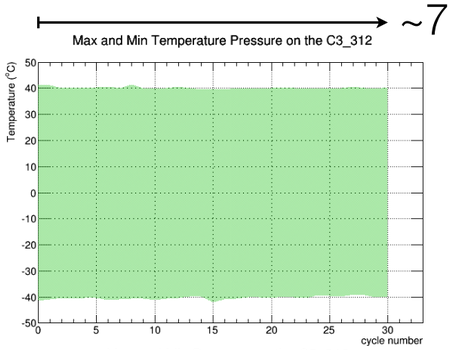
long term cycling and qualification

- 14 pressure cycles during each temperature cycle

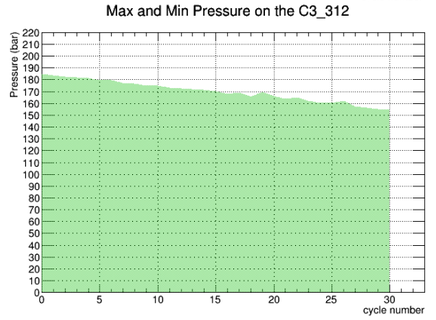


~7 hours

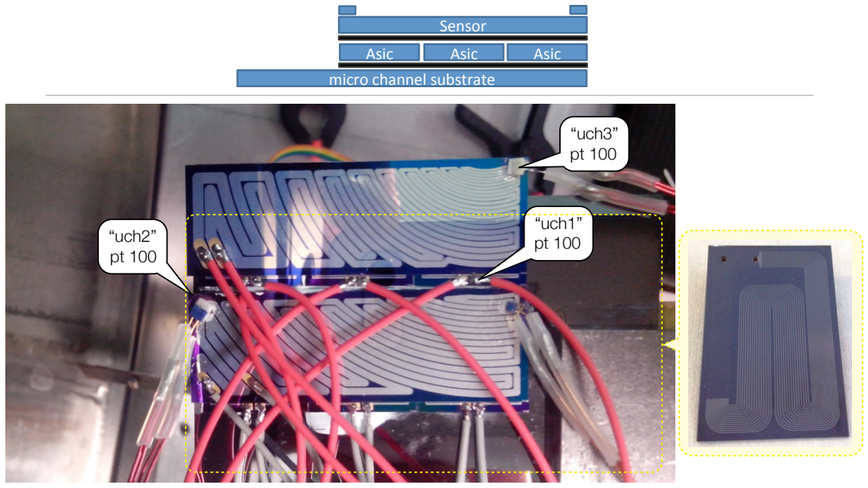
80°C range
[-40°,40°]



170 bar
[0,185max]



Example of sample tested over 30 cycles

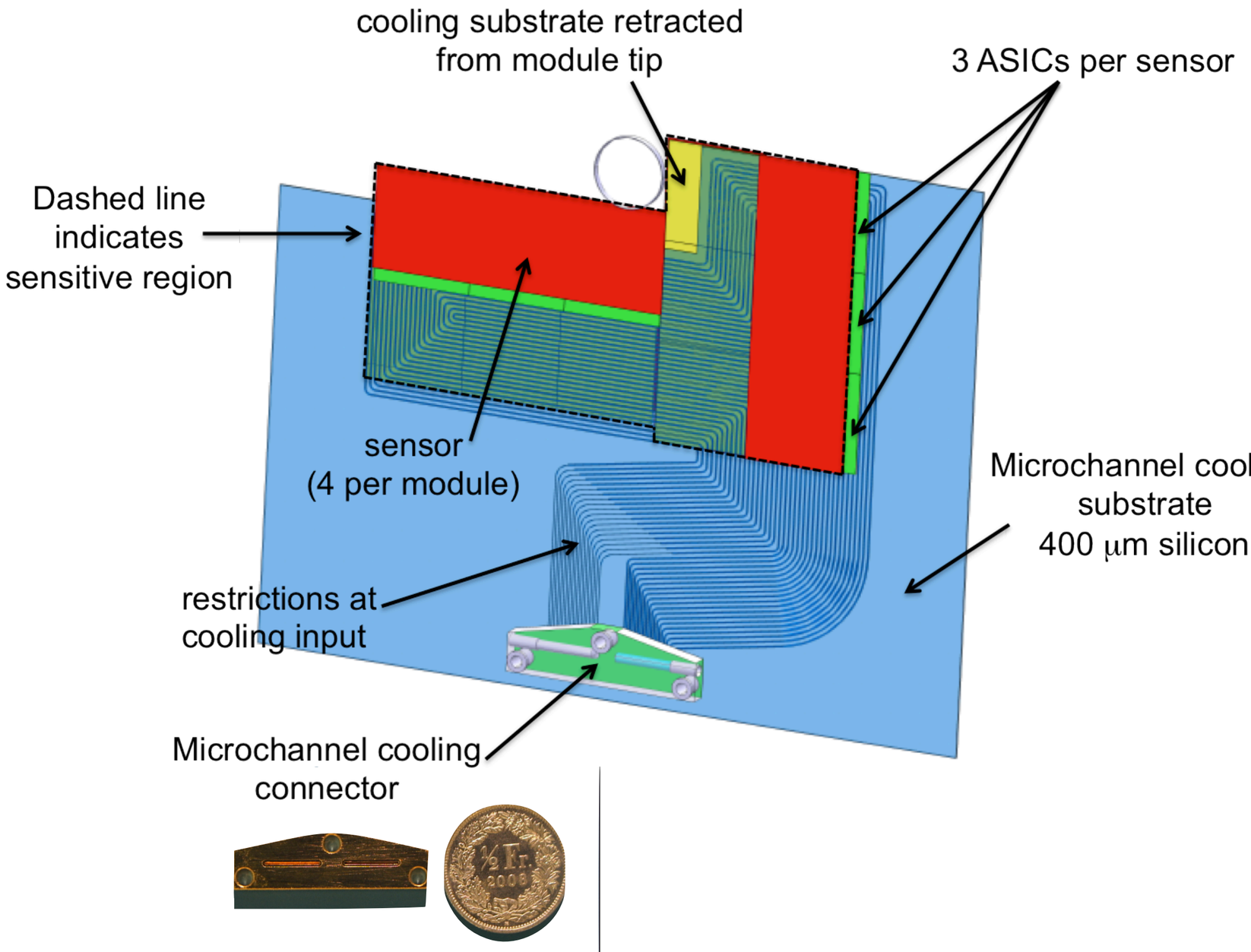


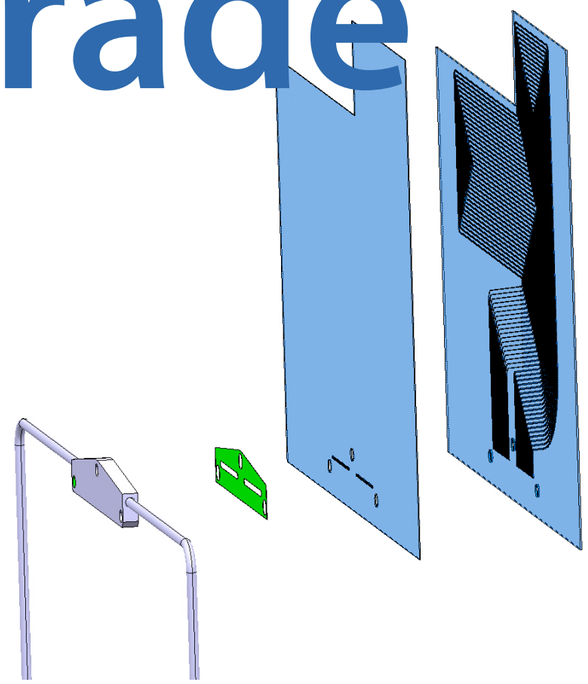
Required heat-sinking demonstrated with a 1/2 module mockup

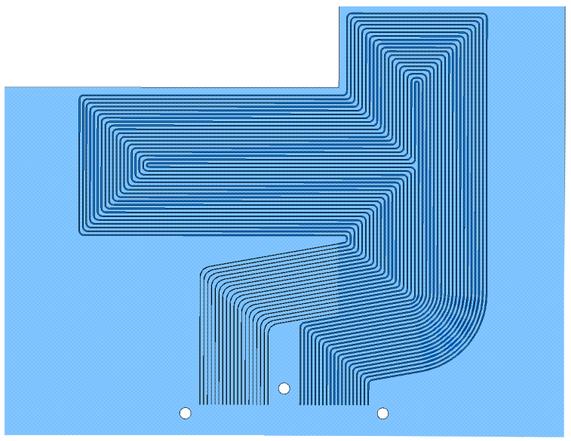
from M. John https://indico.cern.ch/contributionDisplay.py?contribId=8&confId=233332

LHCb VeLo Upgrade

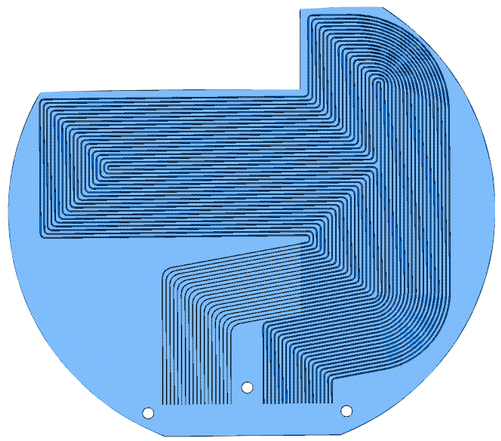
final design







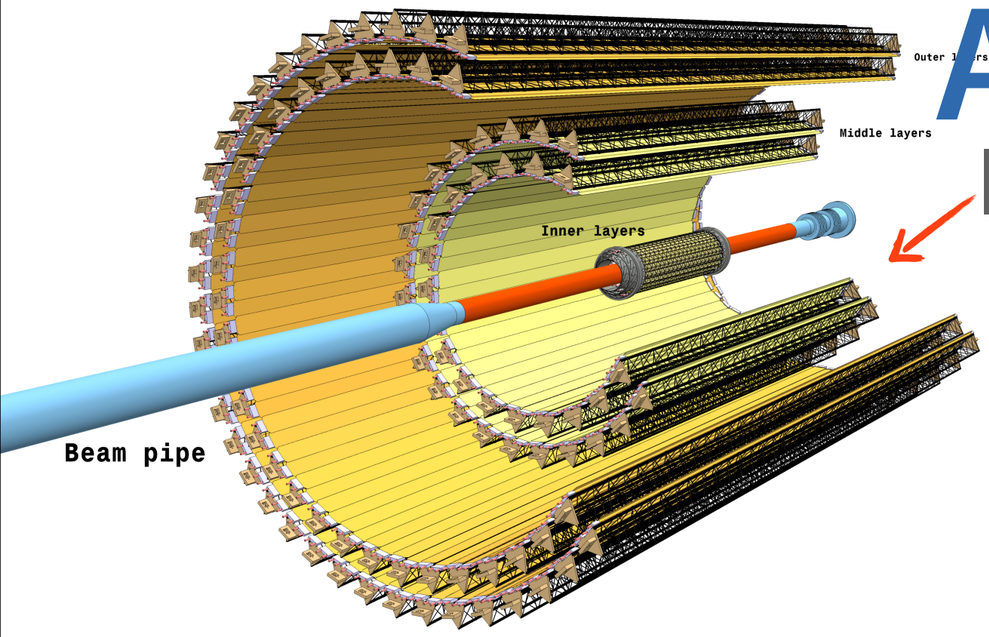
Fabrication by CEA Leti-3s



Prototyping at EPFL on 4" wafers

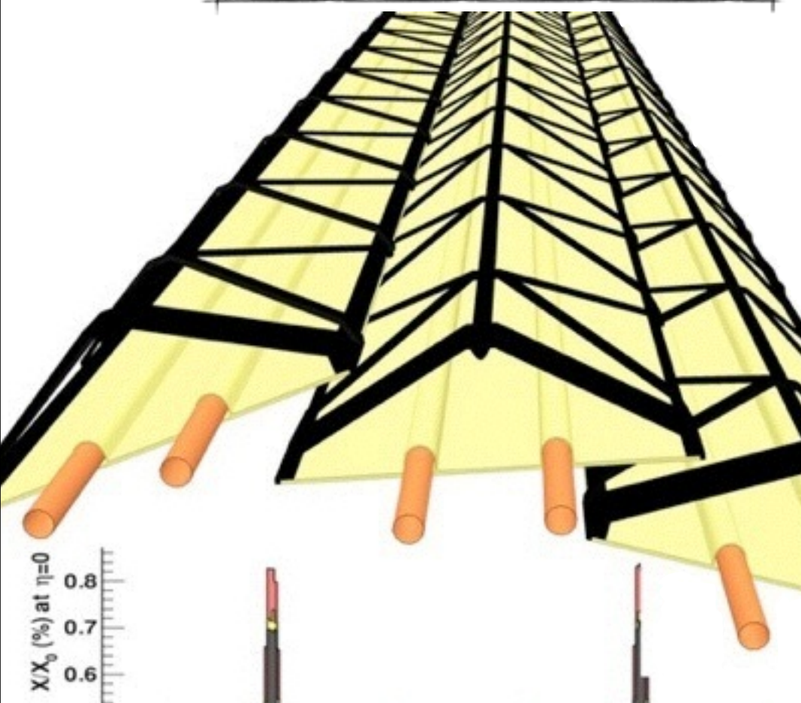
ALICE ITS Upgrade

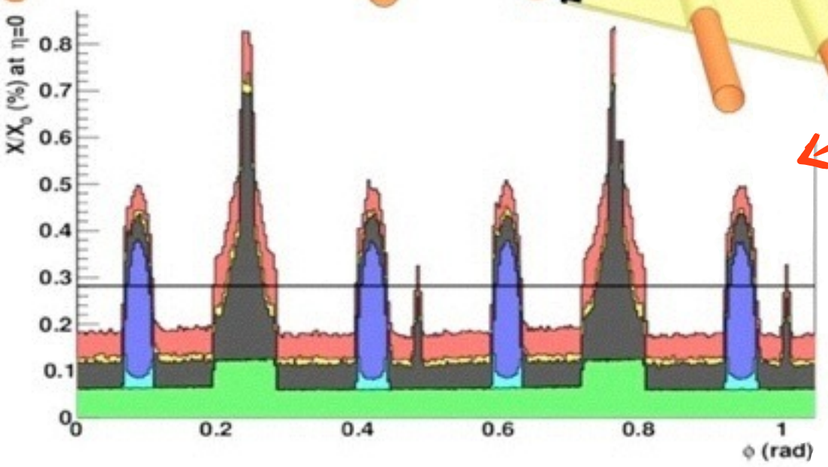
Inner Layers

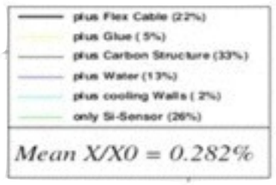


Baseline Solution

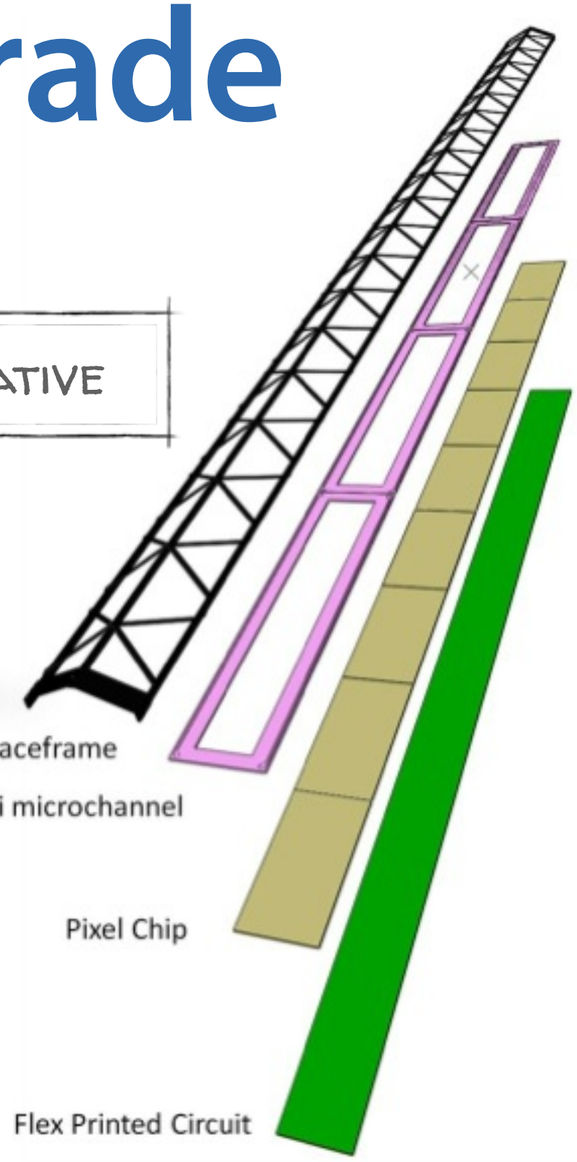
C. Gargiulo et al.

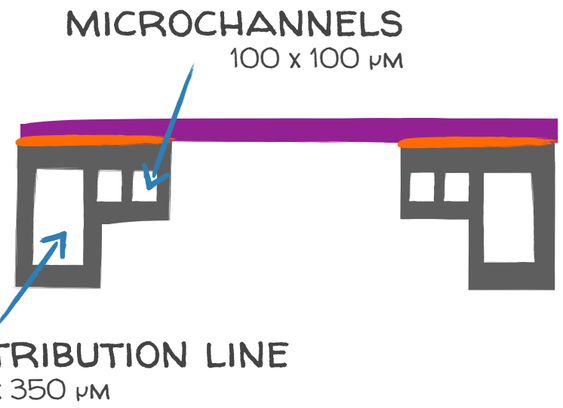


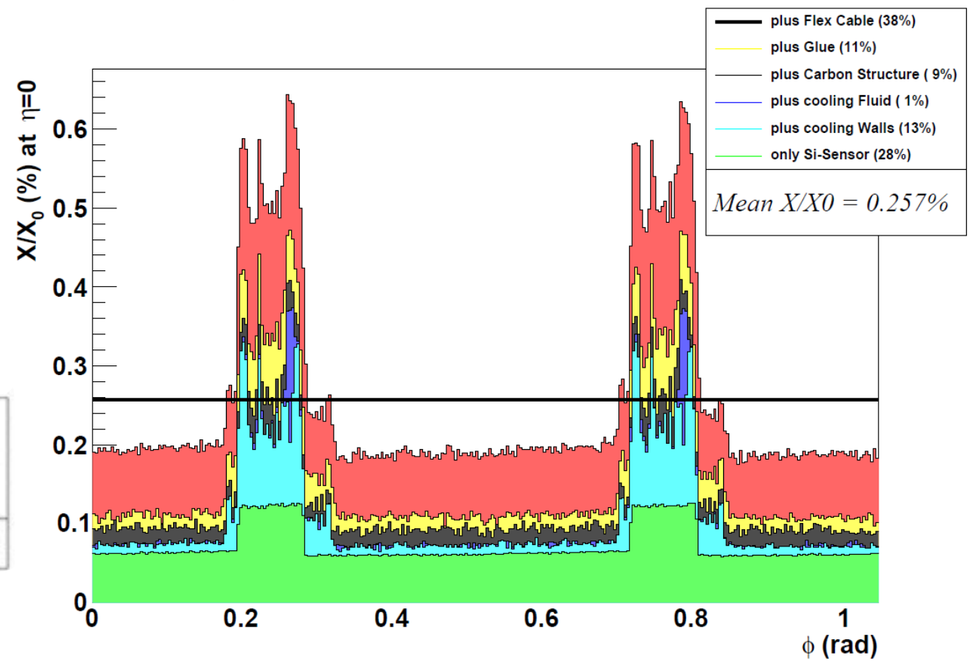




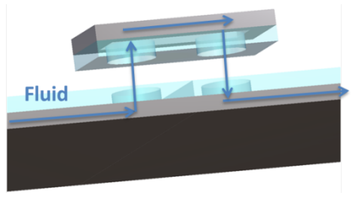
Silicon Alternative

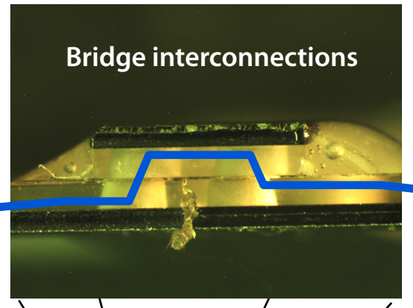




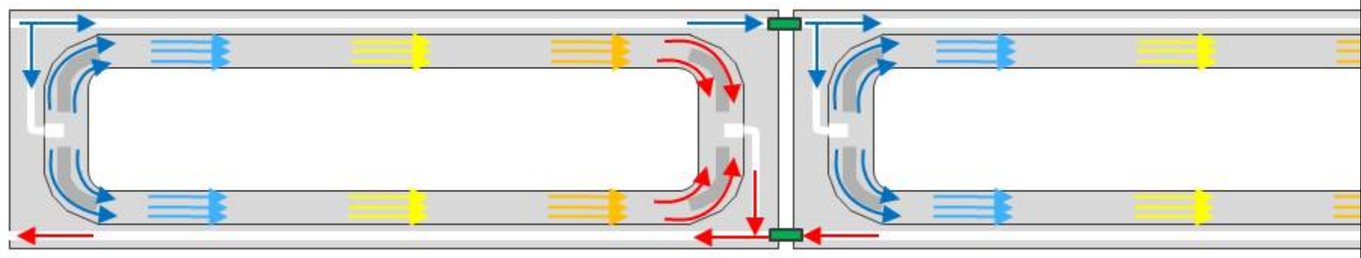


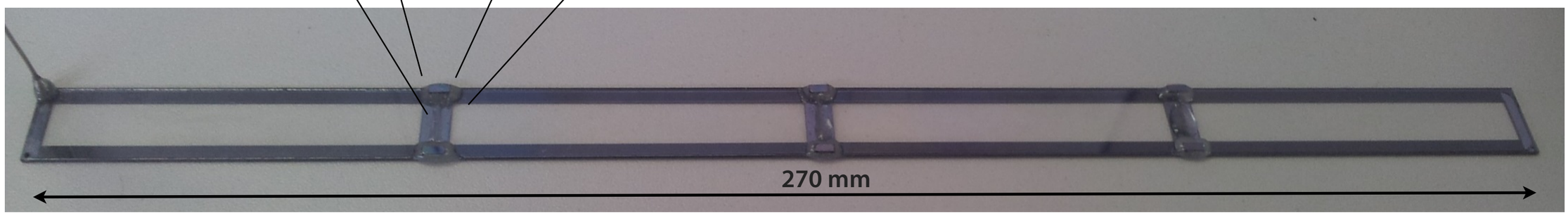
ALICE ITS Upgrade





FLUID PATH

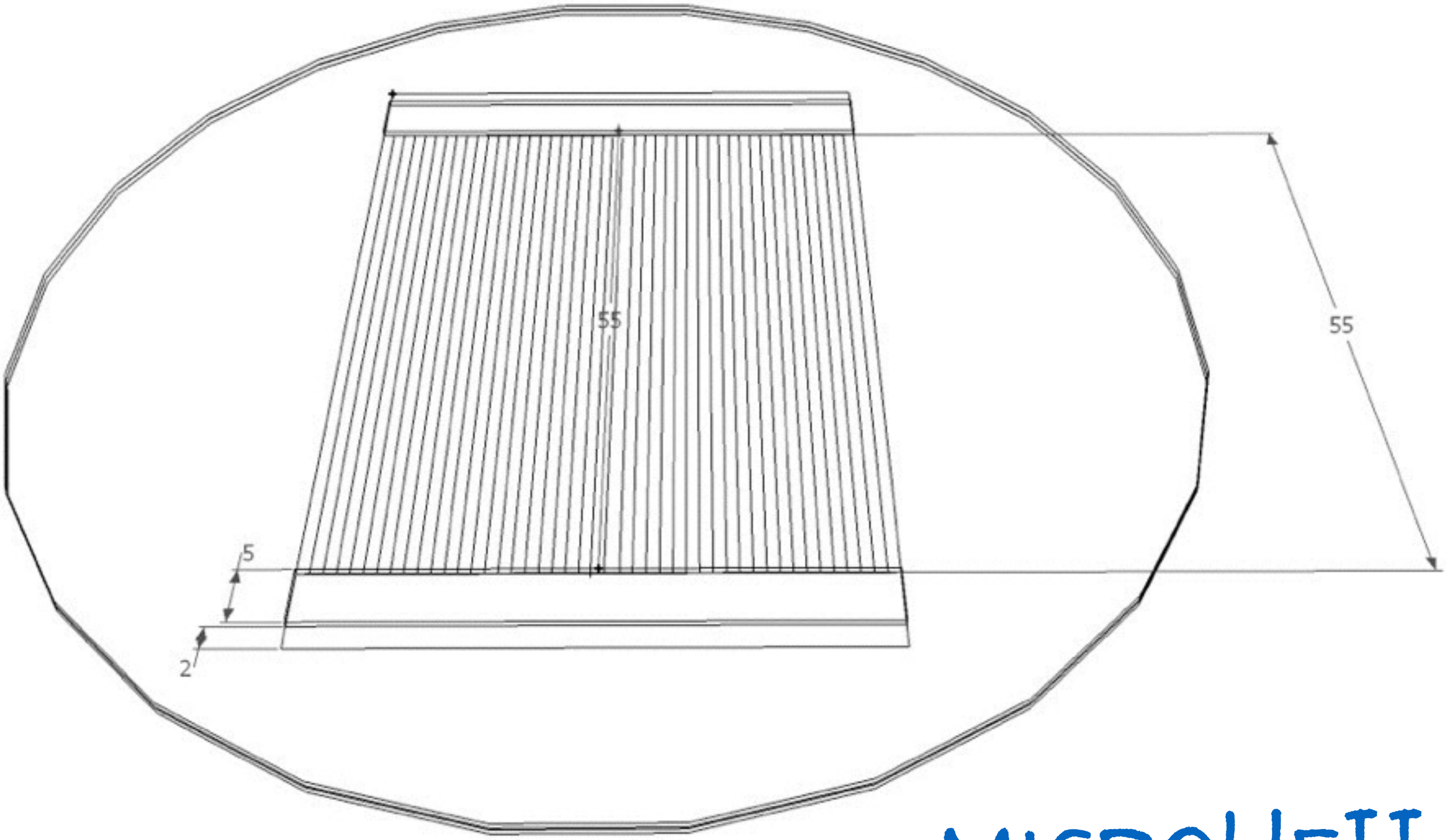




4 frames are required for a stave from 4" wafers.
Only 2 frames required with single interconnection from 6" wafers (TMEC, Thailand).

9x silicon dummy chips with thin metal film (heater) glued on top of the stave.
Thermo-fluidic preliminary tests have started demonstrating the principle of operation.

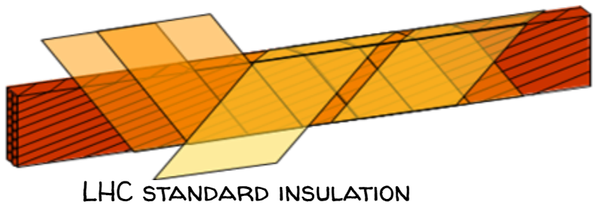
HEAT TRANSFER OF SUPERFLUID HELIUM



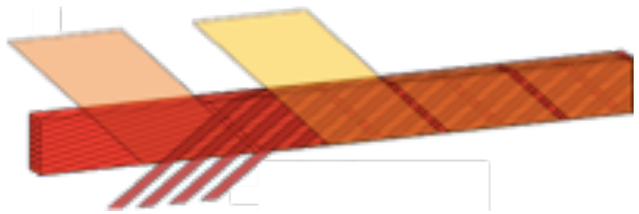
MICROHEII

Study the heat transfer of superfluid HeliumII in microchannels

thermally-enhanced insulation of LHC magnets

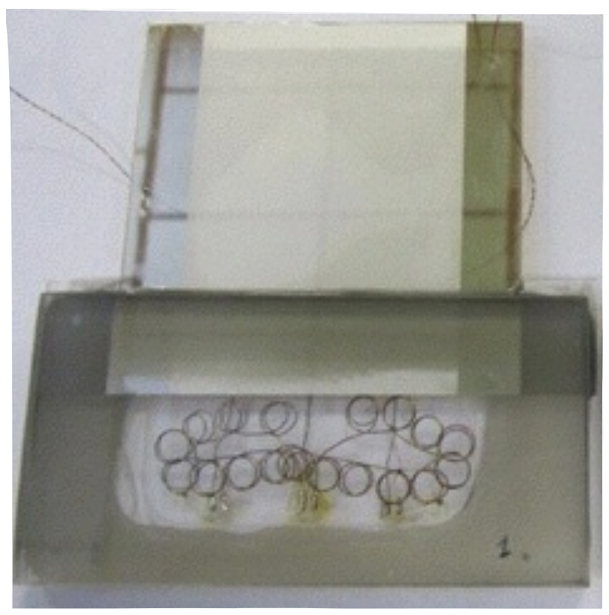


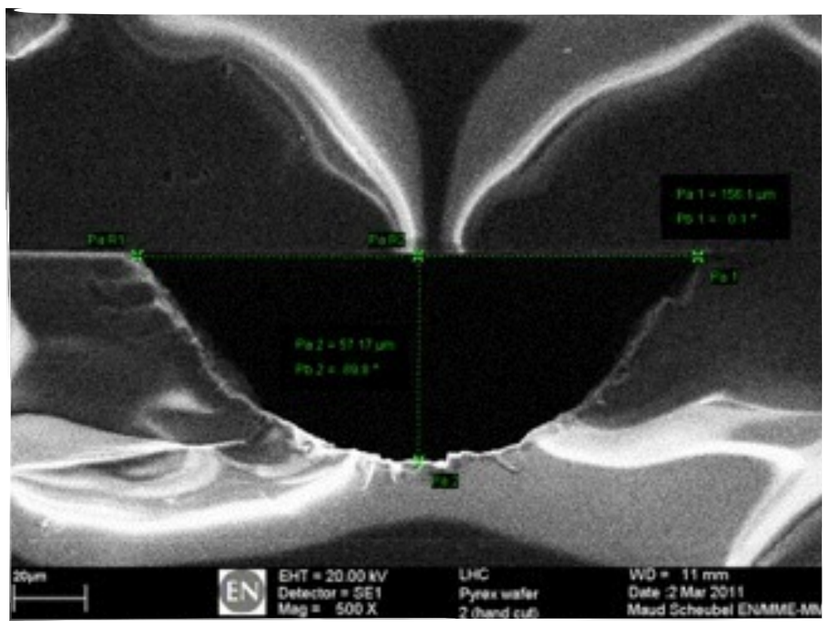
LHC standard insulation



Enhanced insulation for LHC upgrade

Sample	MEMS technique	Number of channels	Characteristic dimensions (μm)	Total Channels Area (mm^2)	Length (mm)
1	Sandblasting	158	$\Phi_{equivalent}$ = 100.4	1.25	55
2	HF etching	172	17.15 x 75.1	0.22	55
3	DRIE etching	1000	~15.8 x 24	0.38	55





P. P. Granieri, et al., "Steady-State heat transfer through micro-channels in pressurized He II"
AIP Conf. Proc., 1434 (2012) 231-238

Conclusions

Microfabricated devices provide many advantages and potential applications for HEP.

Within the PH-DT group, microfabrication techniques have been successfully used for

the development of novel particle detectors (microScint)
alternative ways of integrating services (microCool)
the investigation of heat transport of HeII channels (microHeII)

A great effort still has to be undertaken to study and develop reliable connectivity solutions both in-plane and out of plane.