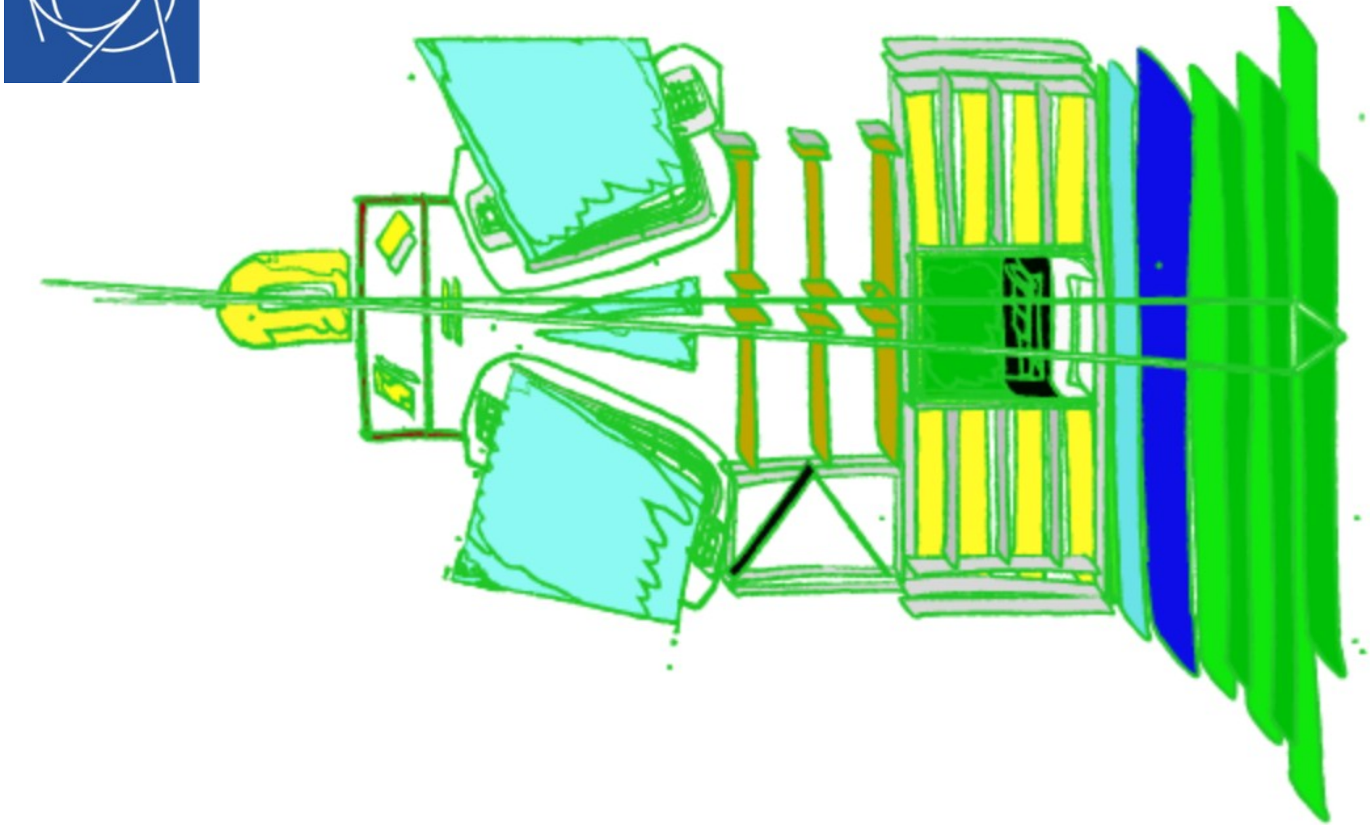
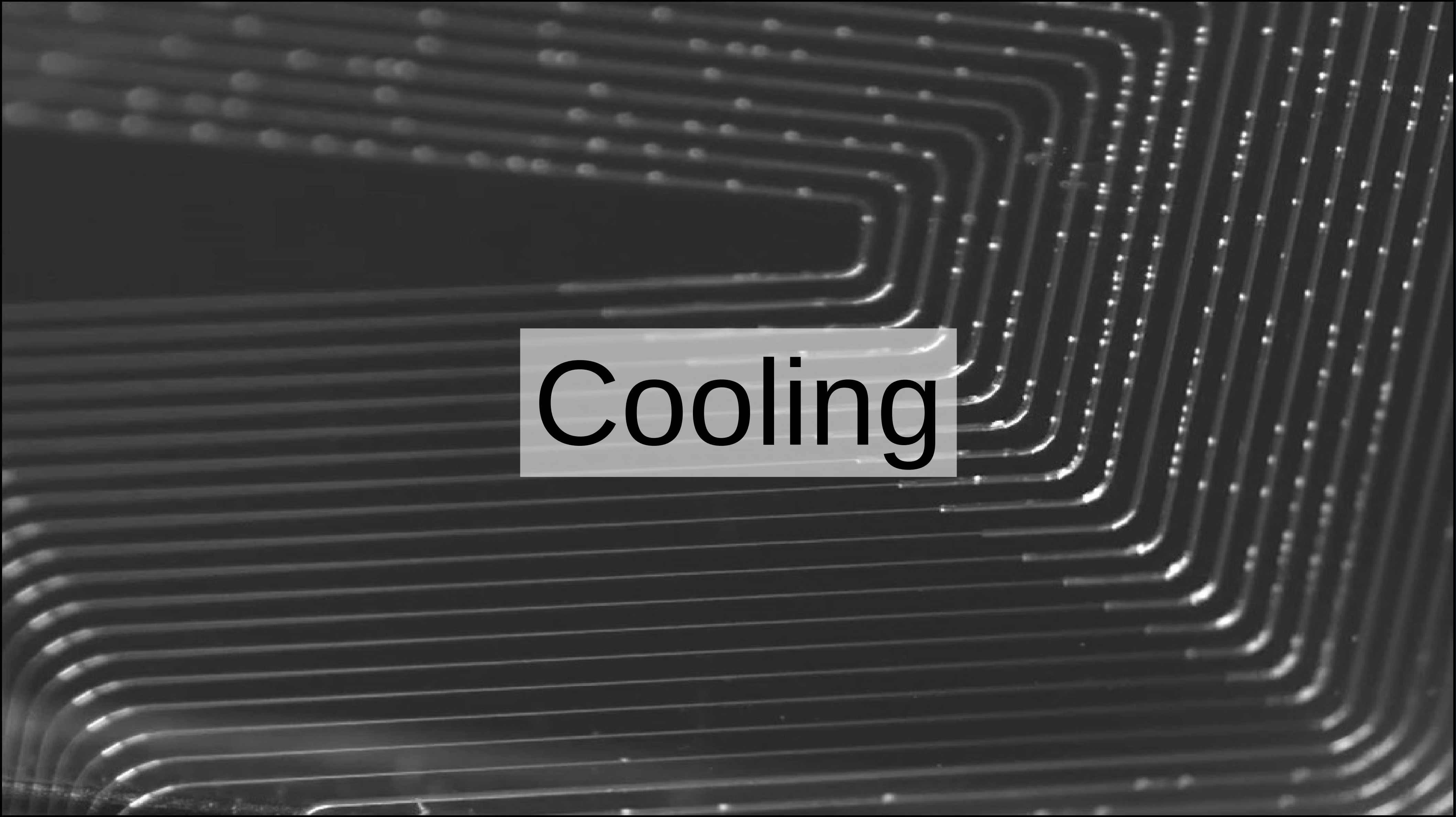


5th Workshop on
LHCb upgrade II

30 .03 - 01 .04. 2020
Barcelona

Cooling, Detector Layout and Mechanics

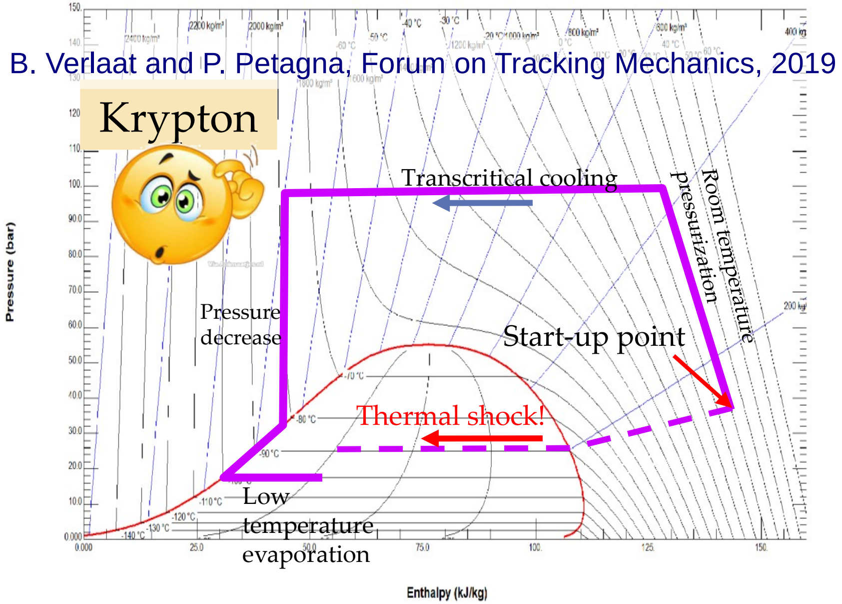
Oscar Augusto on behalf of the LHCb VELO group



Cooling

Module cooling

- Target coolant temperature below -40C
- Evaporative CO2 cooling is reaching its limit (triple-point at -56C)
- New coolants R&D needed: N2O(-163.65), CF4(-184C), Krypton(-157.4C)

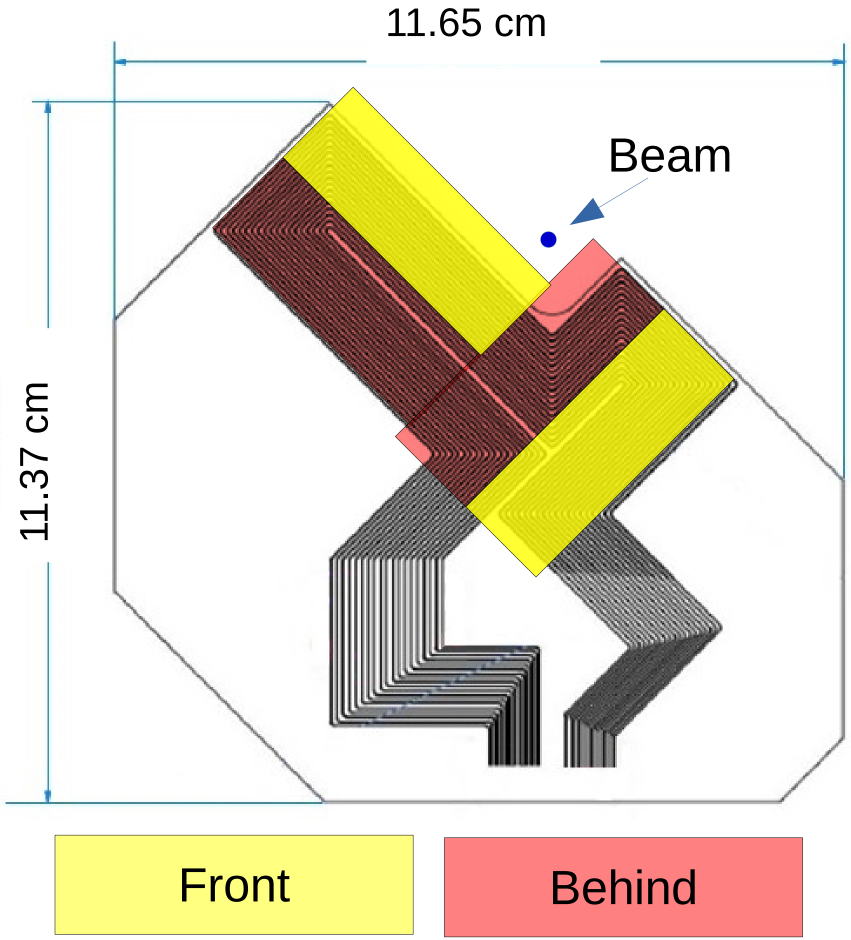

B. Verlaat and P. Petagna, Forum on Tracking Mechanics, 2019

Cooling plate manufacturing

- Silicon microchannels vs 3D-printing
- Cooling performance, CTE mistmatch, tile attachment, reproducibility
- Materials: Titanium, Ceramics, ...

	Si	Al	Ti	SiC
Thermal cond. (W/m.K)	149	237	6.8	120
Thermal Exp. (ppm/K)	2.6	23.1	8.9	2.8
Density (g/cm^3)	2.3	2.7	4.4	3.2

Microchannels etched in silicon



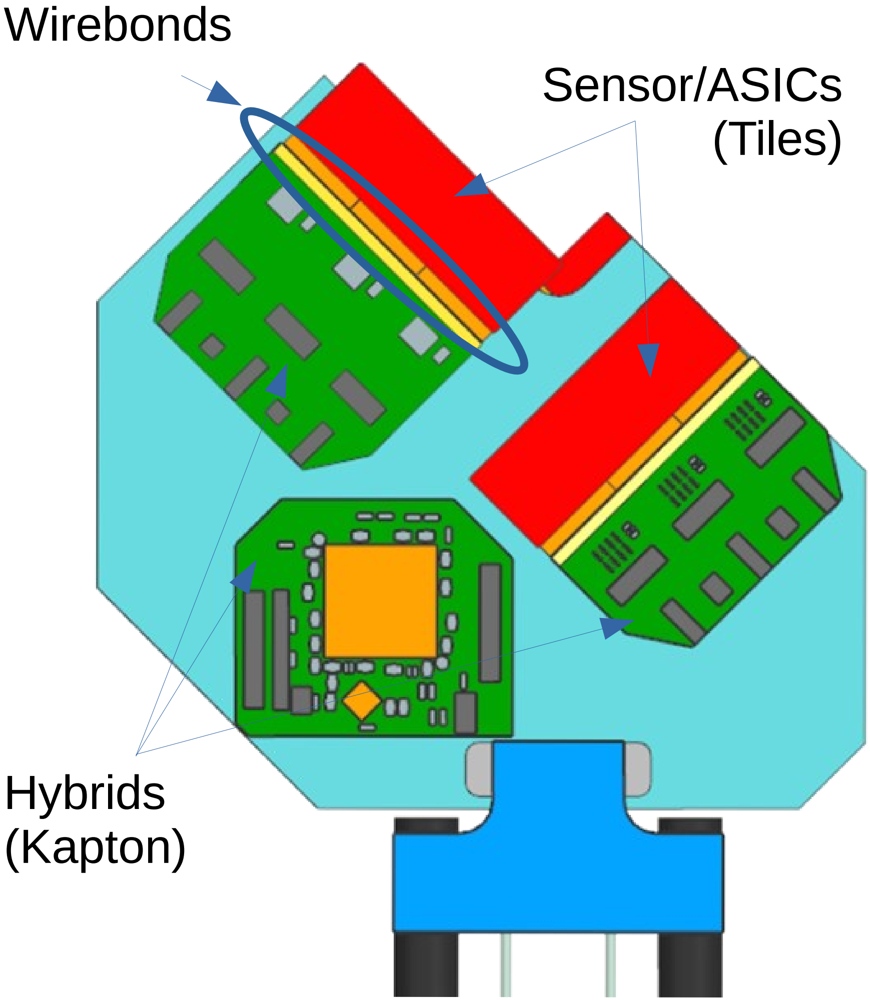
- Narrow restrictions at the entrance
- 60 µm x 60 µm (40 mm long)
- Prevents instabilities among the channels

- Main channels
- 120 µm x 200 µm (~260 mm in average)
- Heat provided by electronics is absorbed by the CO_2 changing the ratio of gas/liquid

- Advantages: High cooling performance, no CTE mismatch to the silicon sensors/ASICs, homogeneous and low mass

- Disadvantages: production cost, CTE mismatch to Hybrids (kapton) mechanically more fragile and integration

Microchannels etched in silicon



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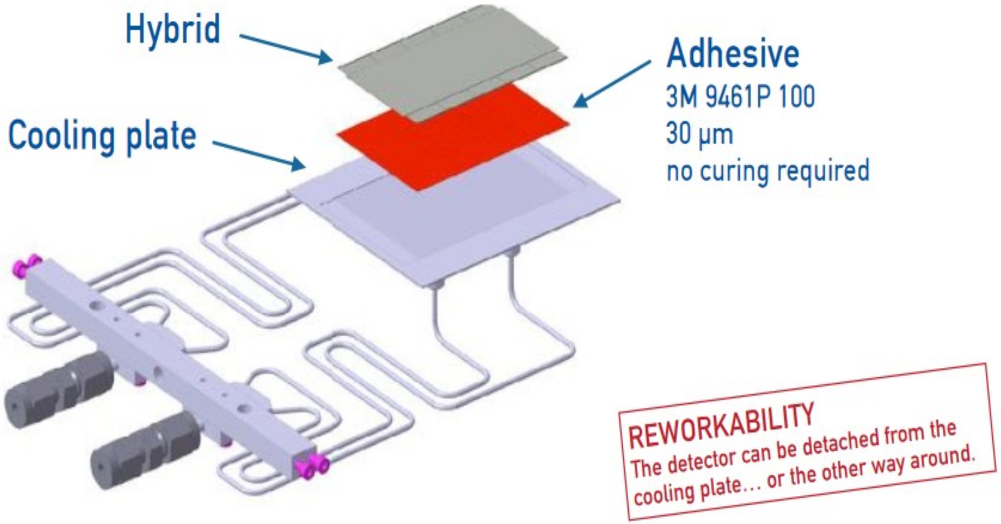
Microchannels Silicon Integration

Reusability

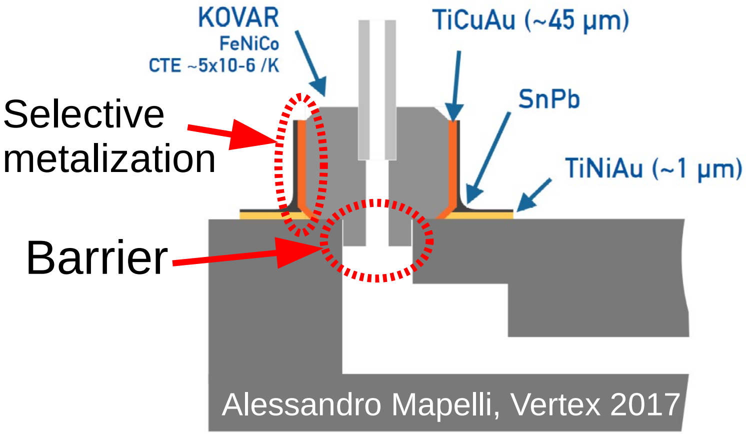
N62 Gigatracker



REWORKABILITY
The detector can be detached from the cooling plate… or the other way around.

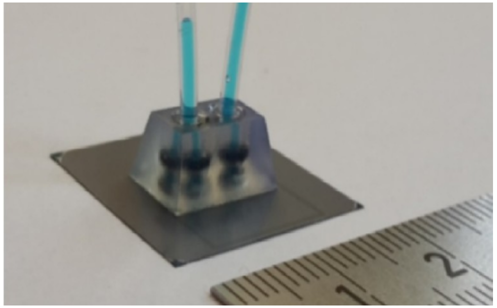
Alessandro Mapelli, Vertex 2017

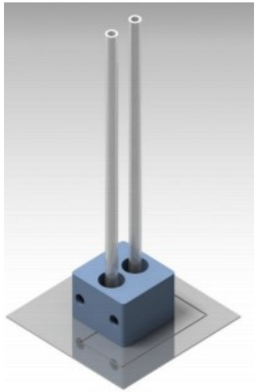
- Improved soldering process



Alessandro Mapelli, Vertex 2017

- 3D printing connectors or mold





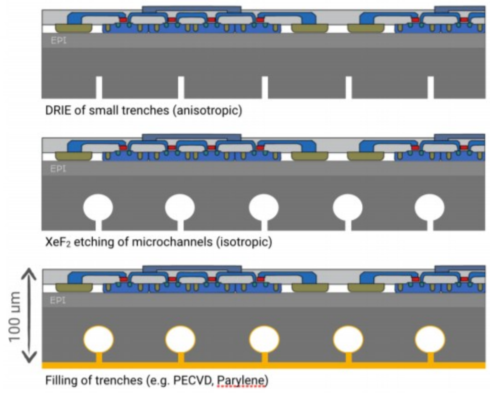
Marcel Vos, Forum on tracker mechanics, Cornell University, June 2019

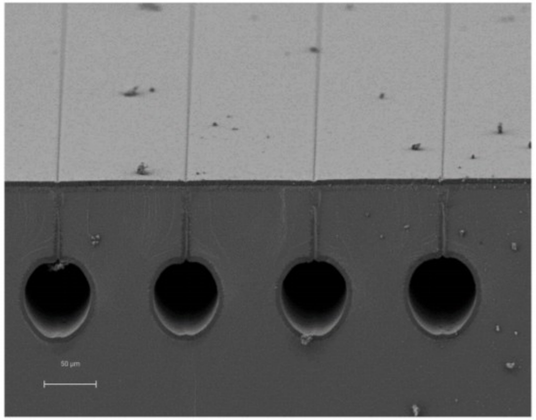
Microchannels Silicon

Production cost
1)Alternative Bonding (Anodic bonding, ...)
2)Smaller cooling plates

Buried microchannels

AIDA-2020-NOTE-2020-003

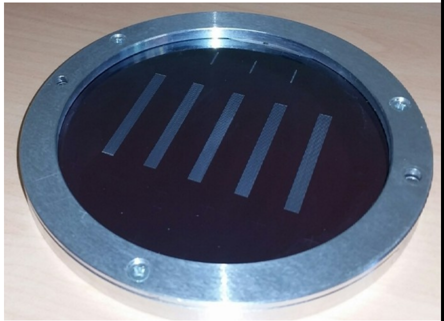


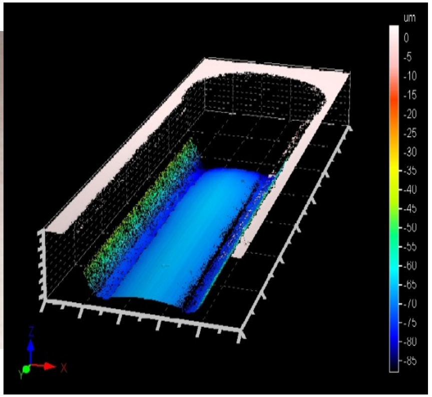


CMOS compatible process
Holds 110 bars
Demonstrator expected soon

Most ambitious approach: bring the cooling to the tiles

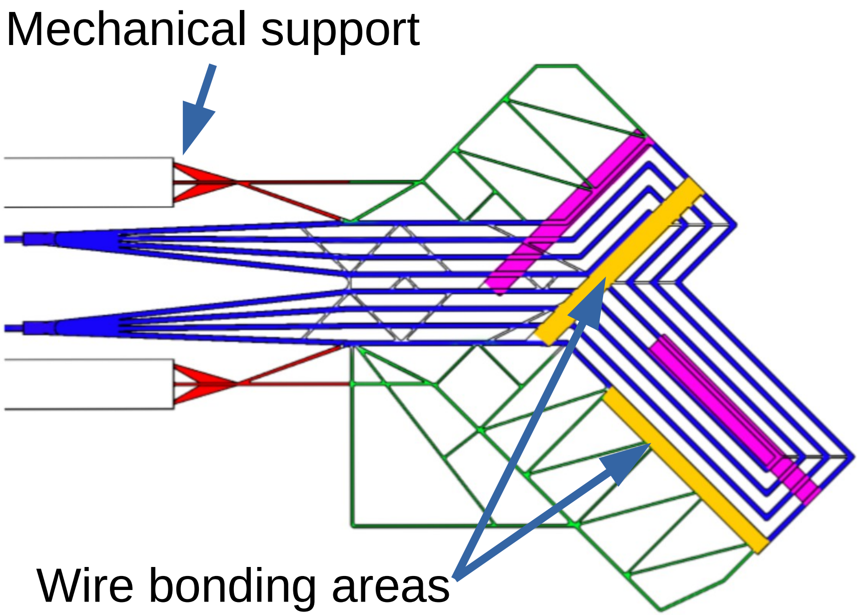
R&D @ CPPM
1)Laser etching and anodic bonding
2)5 x 10 channels per wafer
3)200µm x 70µm x 4.5cm per channel
4)Next step: connector with anodic bonding

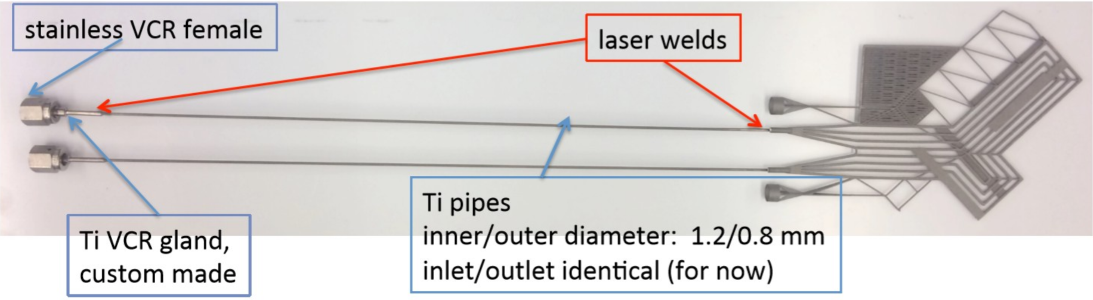


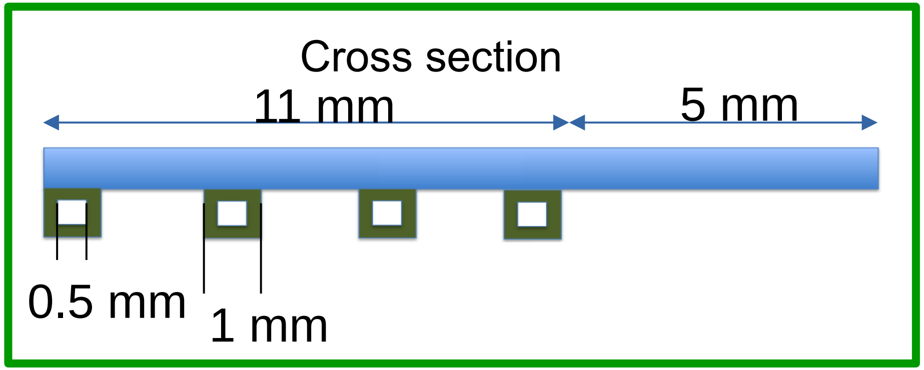


Ti 3D printing

- Material: grade 2 Ti
- Easier to handle (compared to Si)
- Easy to weld
- Cheap (~250 EUR excluding welding)
- Fast turnaround for design changes (few weeks)
- Fast production: 25/batch, 1 batch/ few days
- Restrictions can be integrated in the inlet (0.35 mm x 0.35 mm x 40 mm)

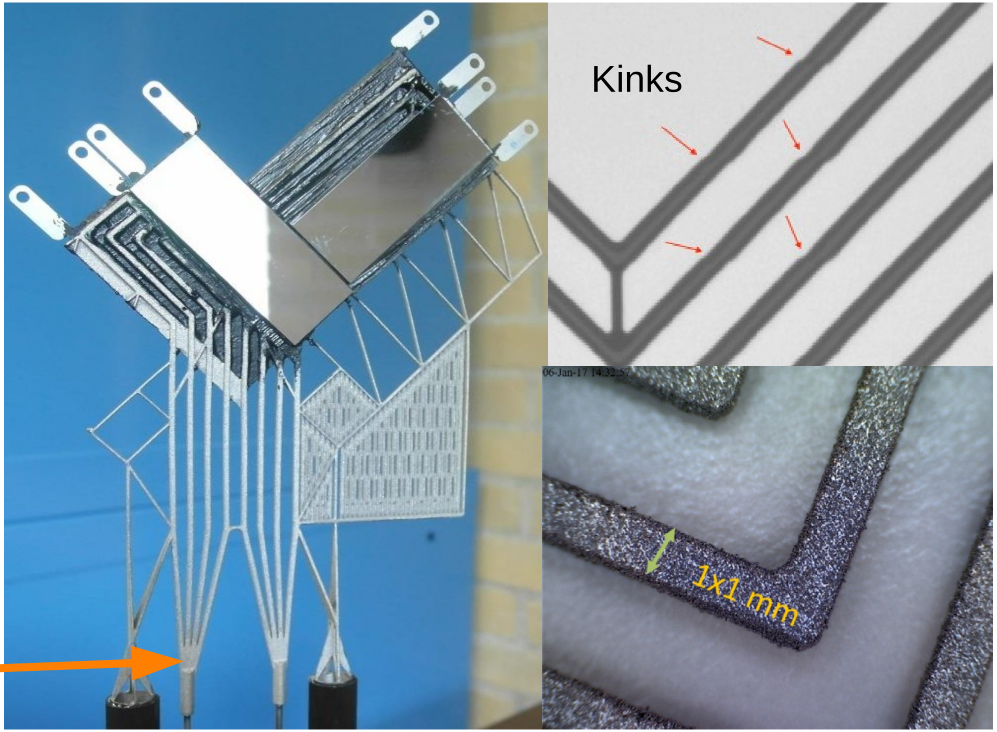


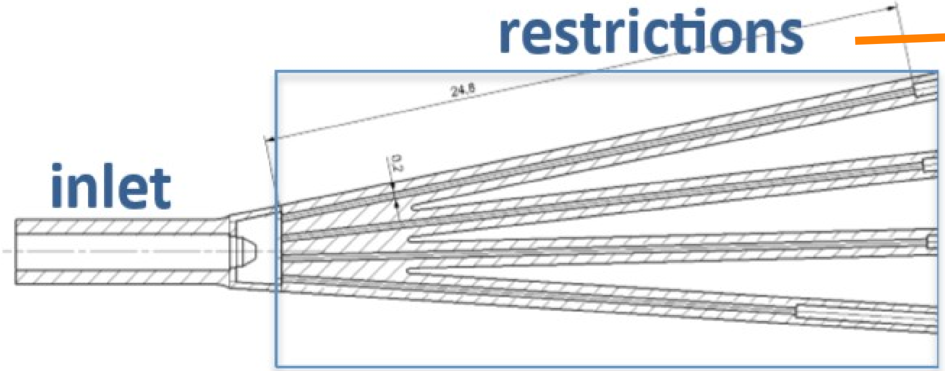




Ti 3D printing

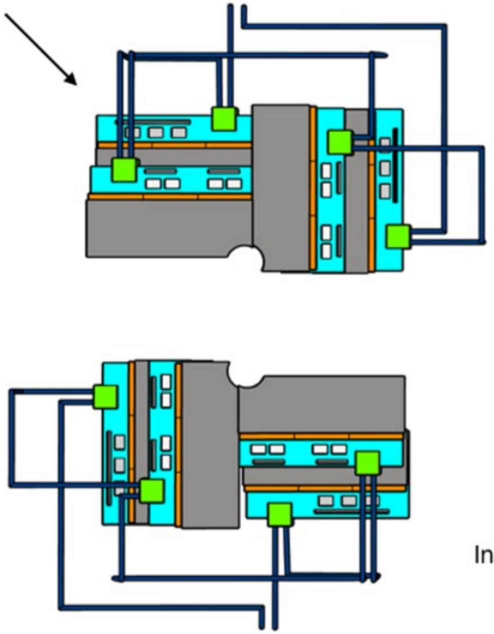
1) Integrated restriction for flow stability
   a) down to 200 µm
2) High pressure test (up to 250 bar)
3) Leak tight (at least 250 µm wall)
4) Deflection due to temperature variations
   < 100 µm
5)Better CTE mismatch to the Hybrids



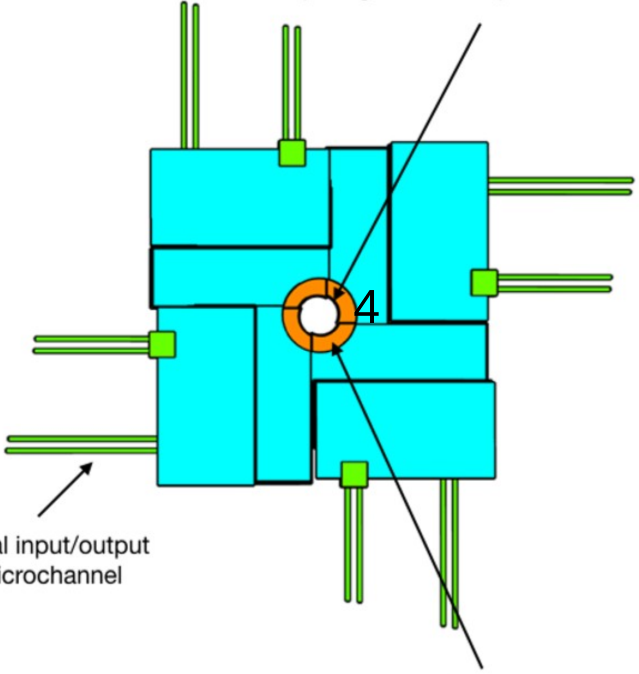


Disadvantages:
1) Low thermal conductivity (16 W/m K)
2) CTE mismatch (6 ppm/K) to Silicon / Glue
   Corresponds to ~14 um variation for Upgrade I
3) Reproducibility

Modules geometry



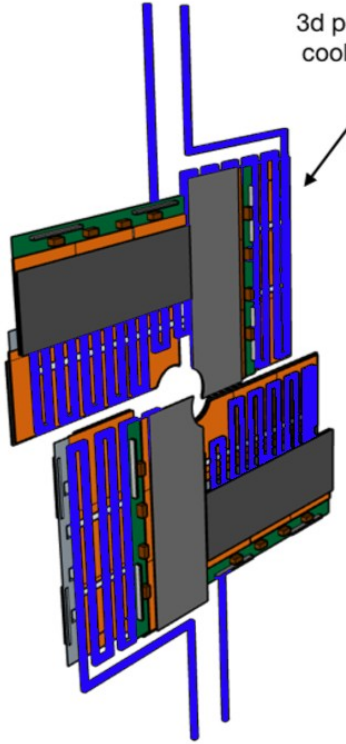
Cooling flowing serially between micro channels



Bespoke dicing on ASIC (dicing lanes incorporated in design)

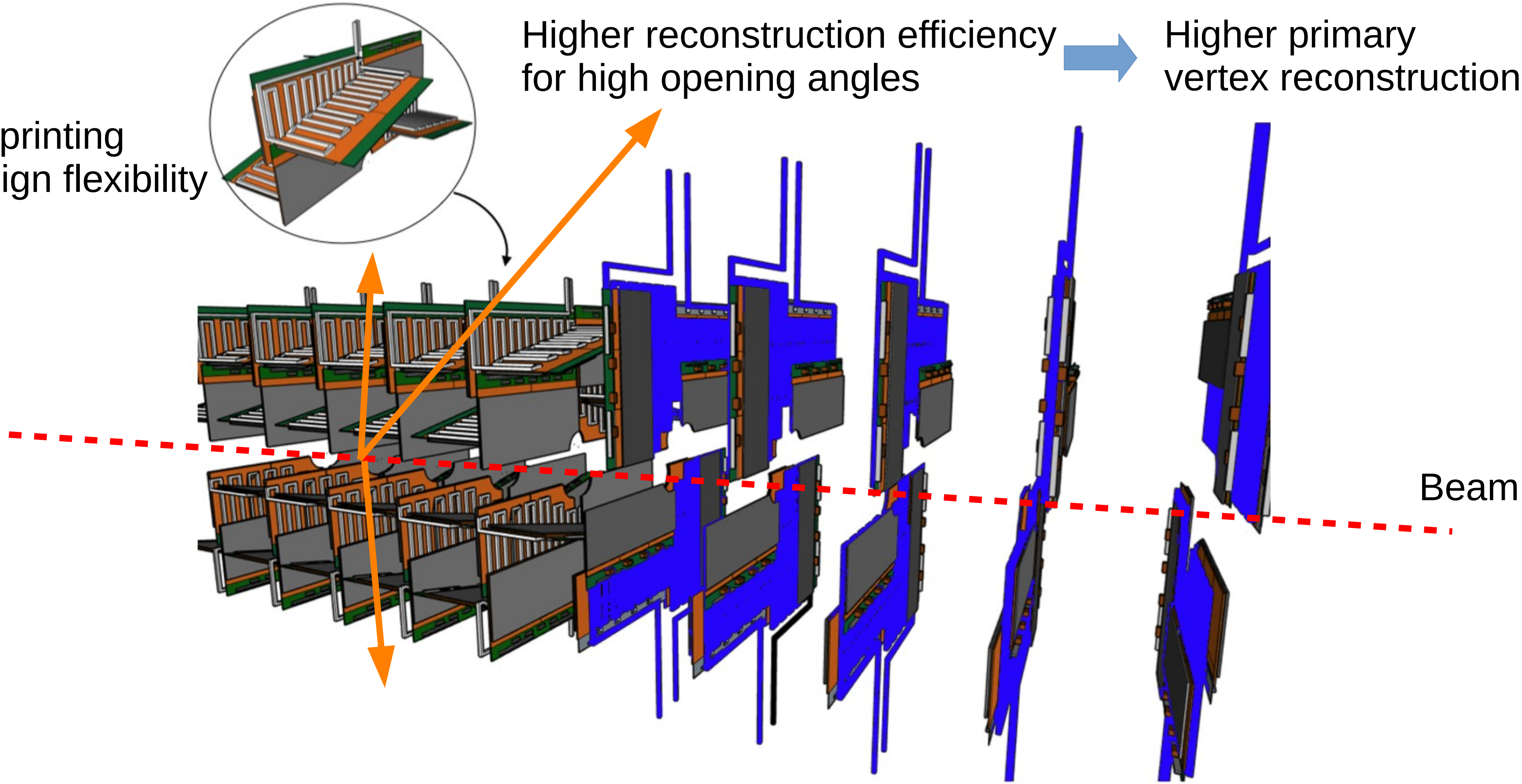
Individual input/output Per microchannel

Overhanging sensor



3d printed titanium cooling backbone

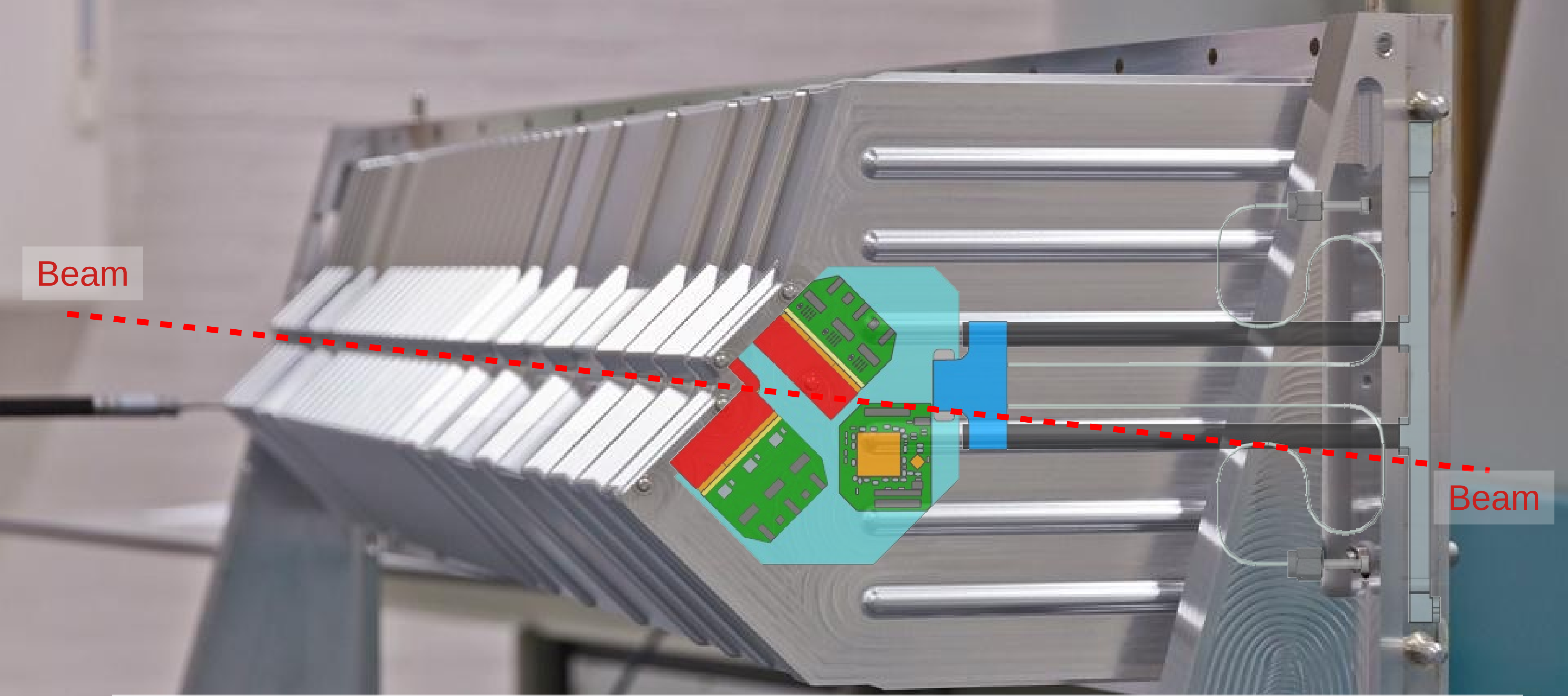
Modules geometry



3D printing
design flexibility

Higher reconstruction efficiency
for high opening angles

Higher primary
vertex reconstruction



“~~To be, or not to be~~, that is the question”

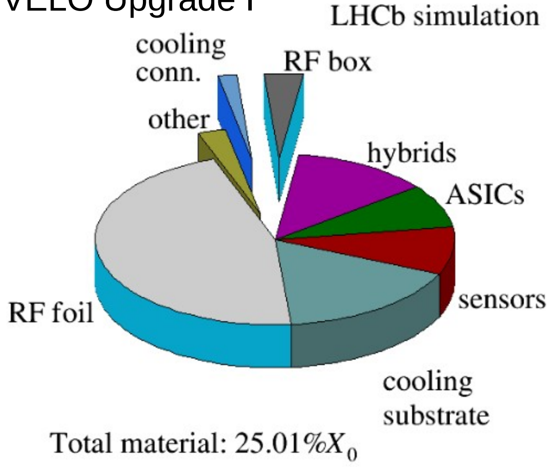
Hamlet

Foil or no foil

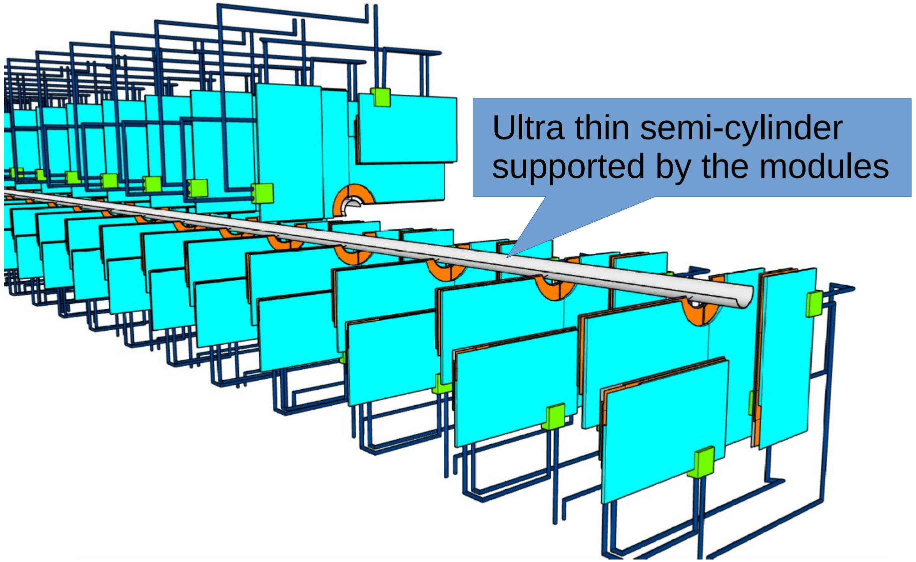
Foil or no foil

- No foil is better for the physics performance
  - Major contribution to the material budget for the VELO Upgrade I
- Module might come closer to the beam (better performance) or profit from the improved performance and move away to reduce radiation damage
- Critical for the design constraints and module replaceability. Radiation hardness changes:
  - 10^{16} neq/cm^2 (replaceable) vs 10^{17} neq/cm^2 (non-replaceable)
- A few ideas:
  - Ultra thin foil supported by the modules
  - Wires weave

VELO Upgrade I

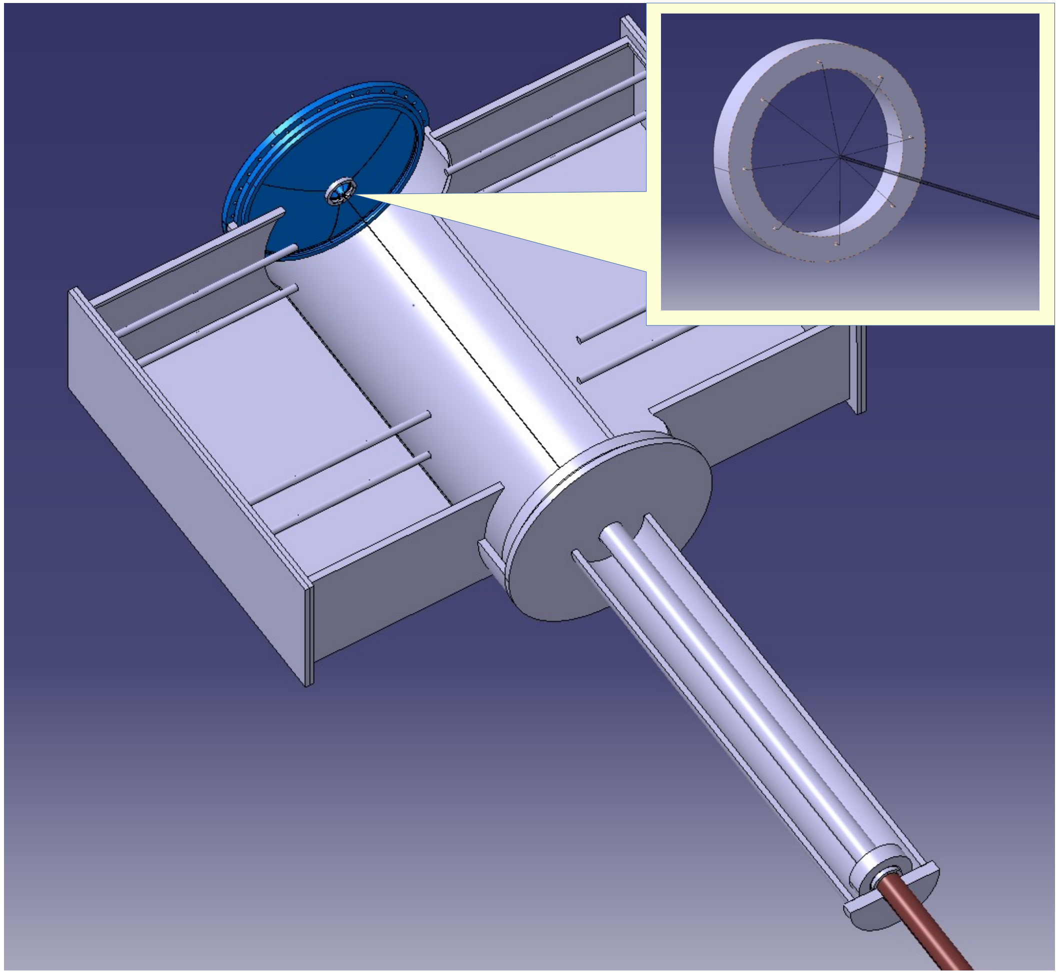


Total material: 25.01%X_0



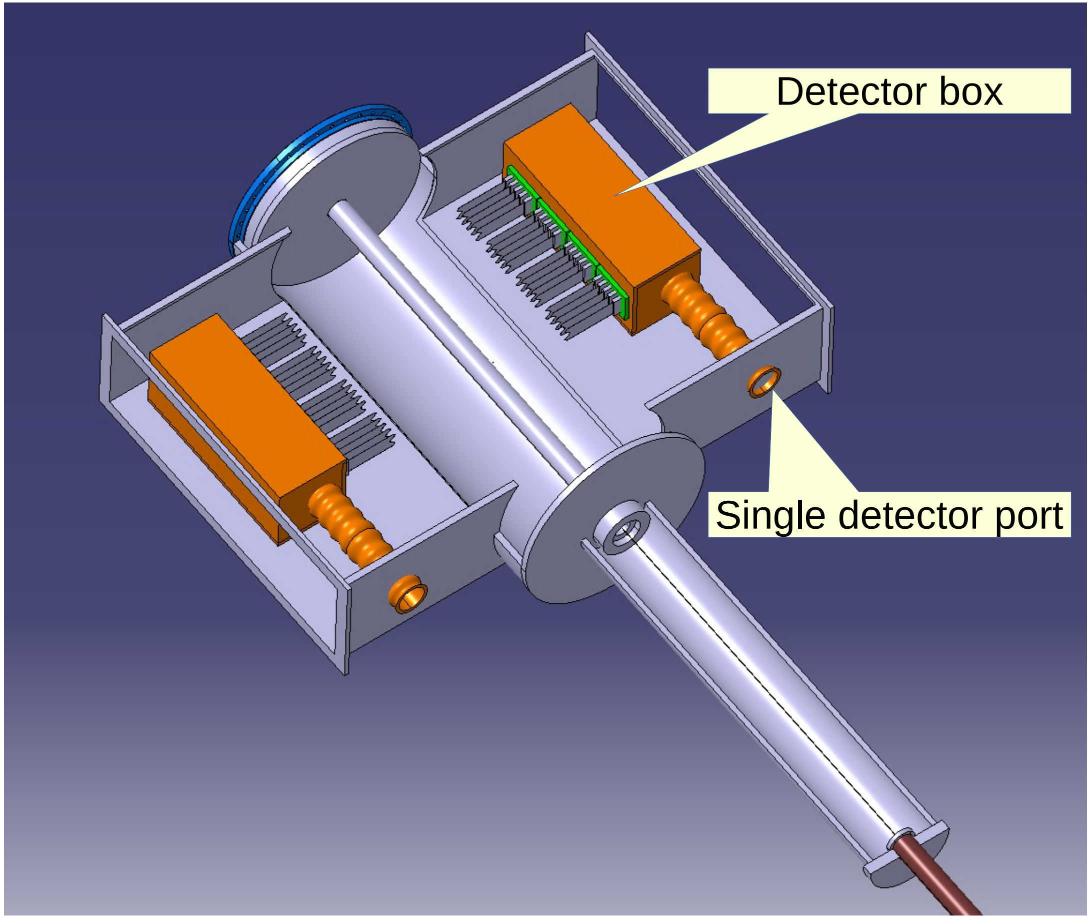
Ultra thin semi-cylinder supported by the modules

Piston and wires concept



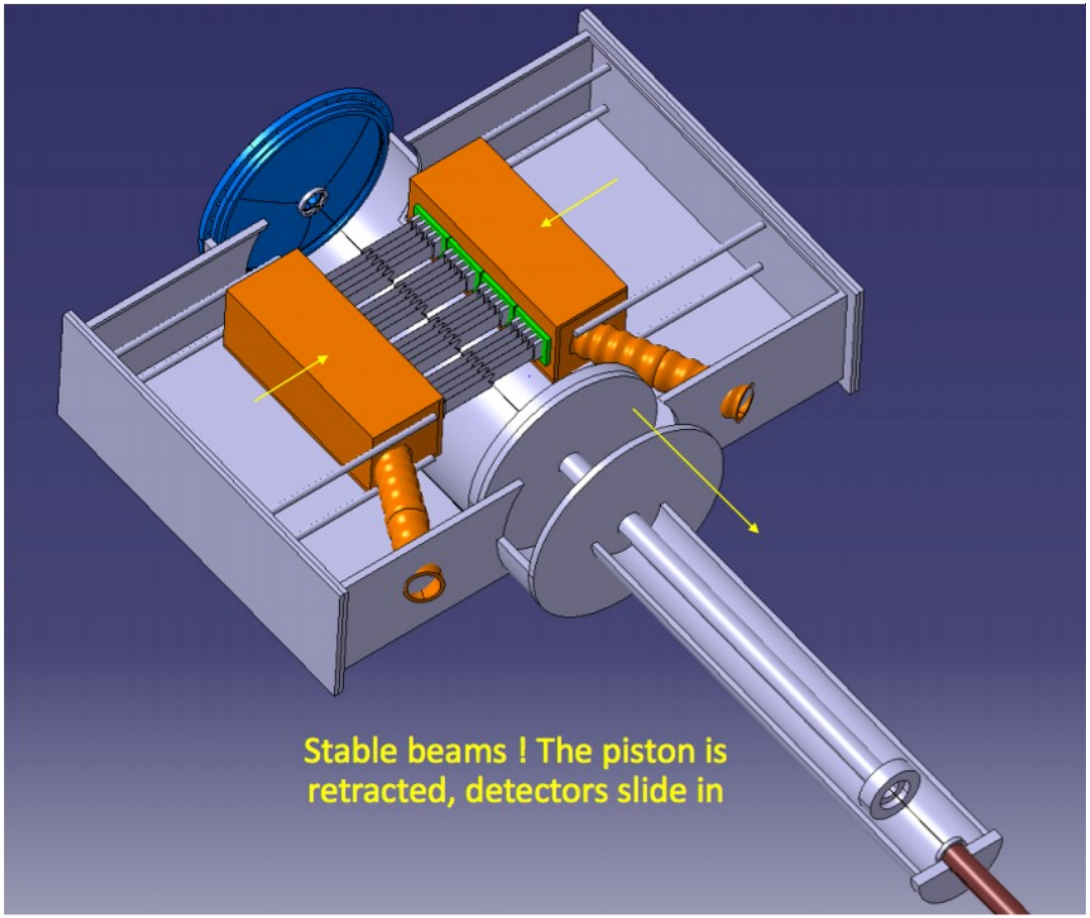
1) Detector is in beam vacuum
2) The image current travels through the foil replacement
3) Wires weaver
   (a) Tungesten-Rhenium gold plated?
   (b) Coated carbon fiber strips or tube?

Piston and wires concept



1) Detector is in beam vacuum
2) The image current travels through the foil replacement
3) Wires weaver
   (a) Tungesten-rhenium gold plated?
   (b) Coated carbon fiber strips or tube?
4) The detector is fully supported by a mountable leak tight detector box structure
   (a) A spare would allow quicker replacement
5) The region below the module base has its own volume
   (a) Outgassing from cables and additional electronics (OPB?) are isolated from the beam vacuum
   (b) Cooling through dry-air flushing
   (c) Cooling provided through the box
6) Single detector port

Piston and wires concept



Stable beams ! The piston is retracted, detectors slide in

1) Detector is in beam vacuum
2) The image current travels through the foil replacement
3) Wires weaver
   (a) Tungesten-rhenium gold plated?
   (b) Coated carbon fiber strips or tube?
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   (a) Outgassing from cables and additional electronics (OPB?) are isolated from the beam vacuum
   (b) Cooling through dry-air flushing
   (c) Cooling provided through the box
6) Single detector port
7) When beams are stable
   (a) Piston is retracted
   (b) Detector halves come closer to the beam

Conclusion

- 3D printing is very attractive
  - Cost effective for replaceable modules and design flexibility
  - Titanium is not the only option (Alumina, SiC, ...)
- Microchannels in silicon are not excluded
  - re-usability and/or cost reduction will be crucial
- Foil or No foil decision has critical implications for the design and module replaceability and mechanics
- New ideas are welcome even the crazy ones… :)

Thank you for your attention!

Backup slides

Micro-cooling @ CPPM

Gregory Hallewell
Julien Cogan
Mathieu Perrin-Terrin
Olivier Leroy
Stéphan Beurthey

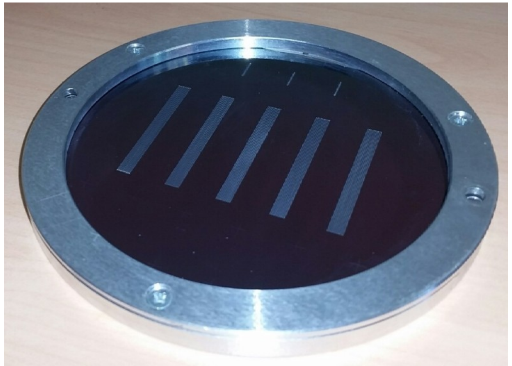
March 2020

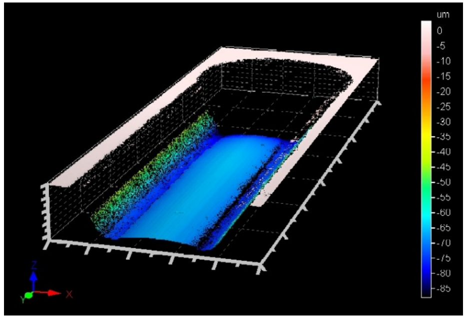
Laser etching

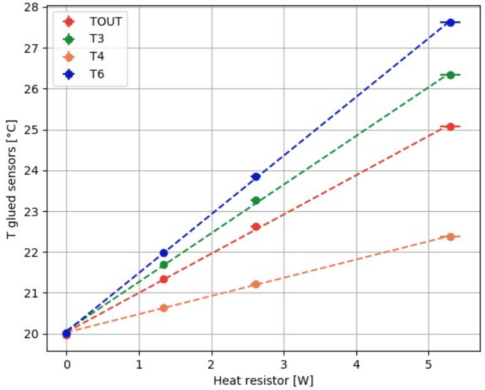
1st experience with micro-channels :

- laser etching of 2 4"-silicon wafers
  - 5x10 channels per wafer
  - 200µm x 70µm x 4.5cm per channel
  - pass-through holes at each channel end
  - with CNRS/LP3 lab, Marseille
- anodic bonding of glass wafer (500 µm thick)
  - with Alessandro Mapelli at EPFL
- thermal and flow tests
  - water circulated at a controlled temperature and flow rate
  - microchannel chips heated with a kapton heater

➢ good for prototyping but probably too slow and not cheap enough for production







Plans

On going: anodic bonding of Si wafers with a thin intermediate layer of glass

- 5 4"-Si wafers etched via DRIE
  - single-ended micro-channel for pressure test with various geometries
  - design compliant with pressure test bench used at CERN
- bonded in Germany
- *currently on hold, next:*
- thinning and dicing
- pressure test @ CPPM

Next, if previous step is successful: start R&D on connector anodic bonding