Mechanics & Cooling Expressions of Interest

04/09/2019

CERN

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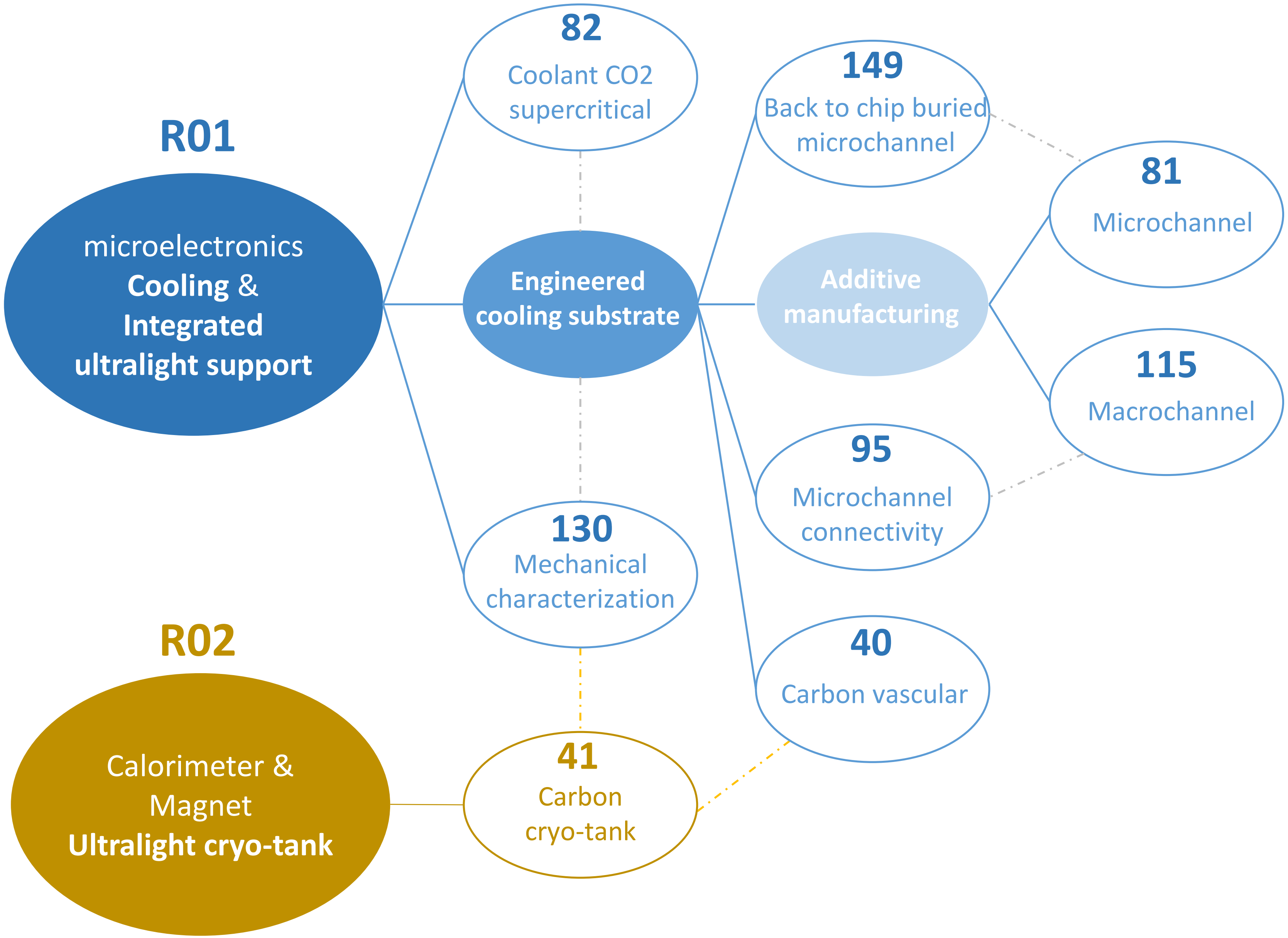
Expressions of Interest

Mechanics & Cooling

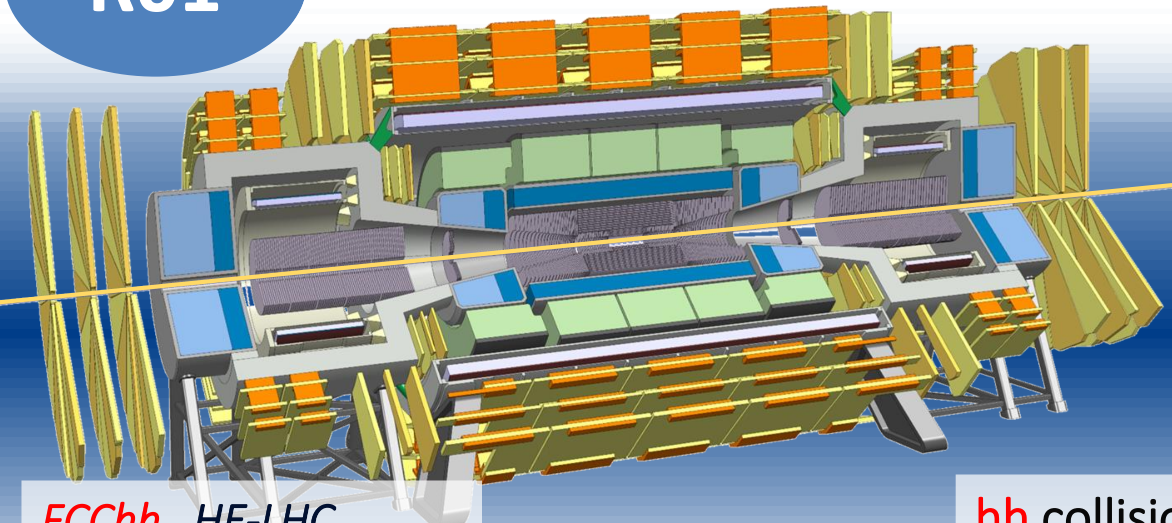
- **40.** Development of ultra-light composite structures with fully integrated cooling
- **41.** Development of ultra-light tanks and pipes for cryogenic fluid and high vacuum applications
- **81.** Ultra-light 3D-printed cold plates for vertexing and tracking detectors
- **82.** Super-Critical CO2 as high performance single-phase refrigerant
- **115.** Design and tests of a cooling plate for 2-phase CO2 cooling in additive manufacturing
- **130.** R&D and performance verification for mechanical support structures for future vertex-tracking detectors
- **149.** Sculpting in silicon: advanced support and micro-channel cooling solutions

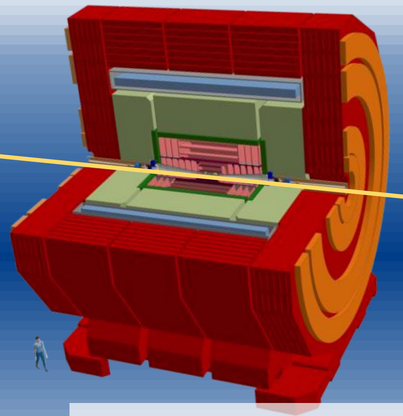
Research Objectives (**RO**)



	Research Institutes	**Industrial partners**
149	CSIC-IFIC, CERN-EPFL, INFN Pisa/Perugia, HLL-MPG, CSIC-CNM/D+T	
81	CERN , CSM	Lithoz GmbH (AT), GF-Machining Solutions AG (CH)
115	CEA	Poly-shape-additive manufacturing (FR)
40	CERN	Workshape (FR)
95	LPNHE Paris, LAPP Annecy (CNRS), CERN	FBK-CMM (IT)
82	CERN, UNIMAN, NTNU (DEPE)	GE Aviation Munich (DE)
130	Univ of Oxford, IFIC Valencia, Univ of Bristol	Etalon GmbH (DE)
41	CERN	Workshape (FR)

R01 High-performance cooling & integrated ultralight support for future detectors





FCChh, HE-LHC, …

hh collisions | e^+e^- collisions

CLIC, FCCee, ILC, CEPC,…

- *High radiation dose (~ 100 MGy/10years)*

Very Low Temperature
High Pressure

- *Unprecedented spatial resolution (1-5 µm point resolution)*
- *Low dissipated power (<50mW/cm2)*

Room Temperature
Minimum Material budget

gas *Air, Nitrogen, He suitable for low on-detector dissipation*

mono phase *WATER "leakless" , FKs, NOVEC, sCO2*

two phase *CO2 CO2/N2O, HFOs*

✓ Future lepton collider ambient temperature viable solution: air cooling or liquid cooling for complex detector geometry
✓ Future hadron collider, more powerful cooling and also lower coolant temperature: CO2/N2O, HFOs, NOVEC?

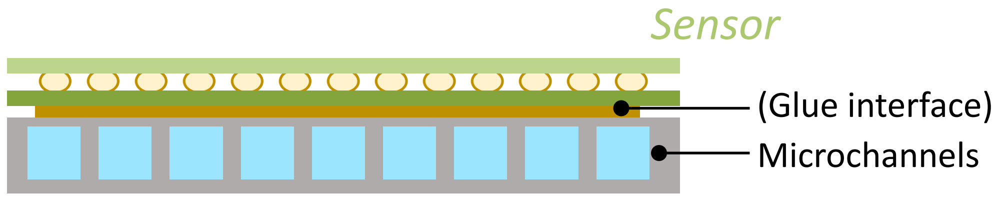
Engineered cooling substrate

R01

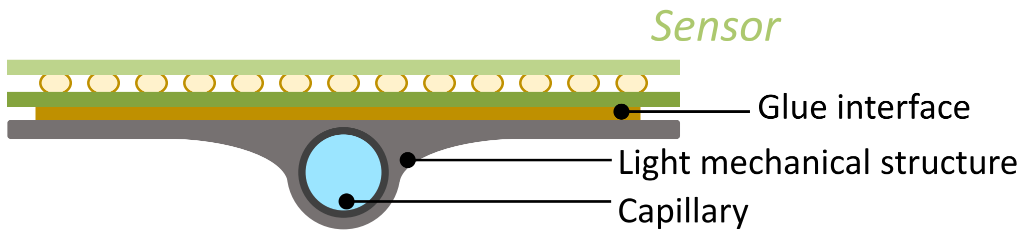
to cool and keep in position next generation sensors

- ✓ *The design of new vertex detectors in lepton collider will have to cope with unprecedented requirements on minimum material budget and dimensional stability. Reduction of material in front of the sensor will be pursued by investigating new air cooling solutions*

Air cooling



Microchannel



Carbon vascular

- ✓ *In hadron collider vertex detectors stringent cooling requirements, driven by the minimisation of radiation damages, will require the development of new heat exchanger substrates to achieve better performance and lower temperatures*

EoI 149

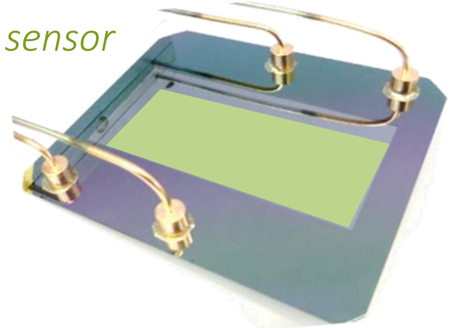
Back to chip buried microchannels

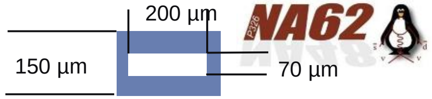
CSIC-IFIC, CERN-EPFL, INFN Pisa/Perugia, HLL-MPG, CSIC-CNM/D+T

Cold plate: silicon microchannel

sensor

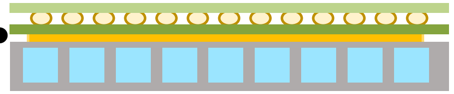
sensor





Sensor

Glue interface



present

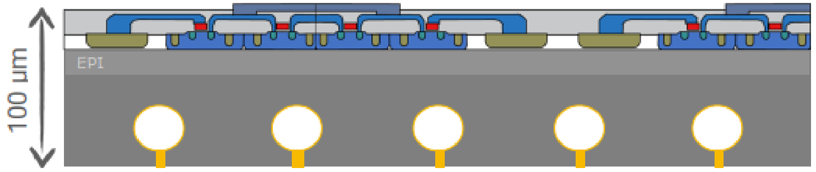
✓ *Silicon microchannel substrate glued at the back of the sensor are integrated in HEP Detectors*

R&D

Engrave cooling micro channels and supporting structure directly on the back of the chip

→ *Demonstrator for the key process steps and process identification*

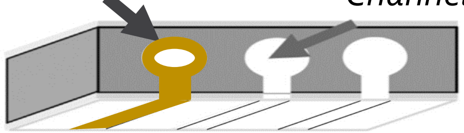
→ *Demonstrator for integrated CMOS ladders with embedded microchannel*

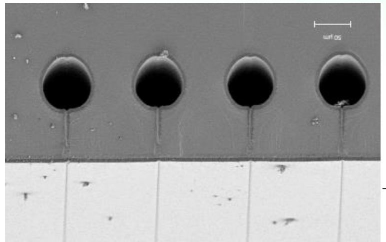


Filling of trenches (e.g. PECVD, Parylene)

Parylene coated channel

Channel





CMi EPFL Center of MicroNanoTechnology

Tests on MALTA chip

future

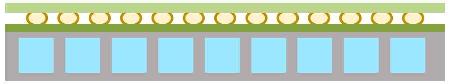
Techniques:

Selective etching and thinning of CMOS detectors

Microchannel in silicon plates with integrated signal and power

Wafer level post processing to incorporate microchannels in CMOS sensors

Sensor



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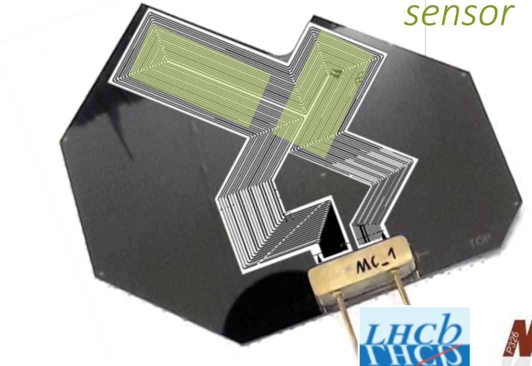
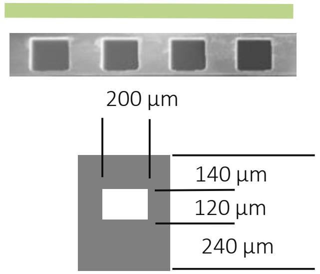
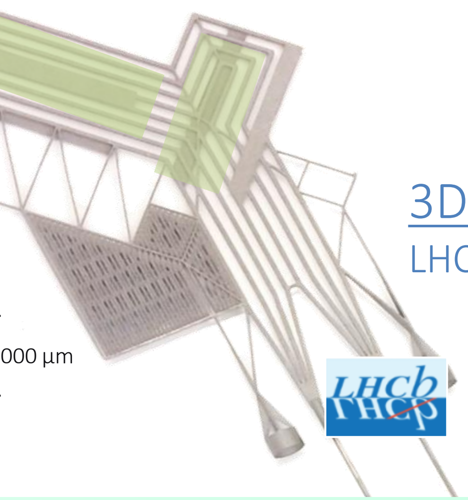
Additive manufacturing: micro-channels

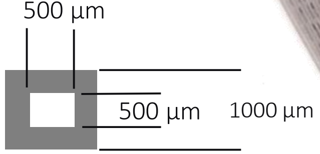
CERN , CSM; Lithoz GmbH (AT), GF-Machining Solutions AG (CH)

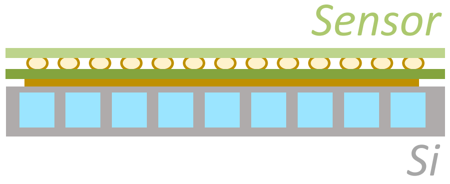
Cold plate: silicon microchannel











present

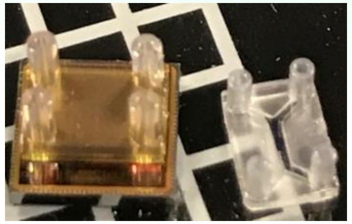
3D printed titanium

LHCB Velo "option C"

R&D

develop cheap and non-planar microchannel substrate

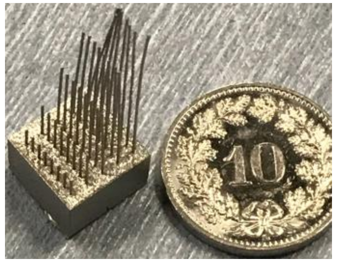
- → *Investigate additive manufacturing processes*
- → *material engineered for compatibility with Silicon sensors (metal, polymer, ceramics)*
- → *Build working prototypes 3d printed in metal ceramics and polymer*
- → *use of AIDA test facilities*



polymer fluidic channels 3D printed on the back of a working CMOS chip

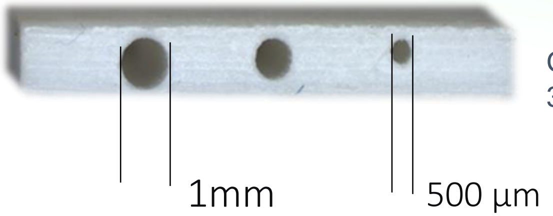
3D printed polymer micro-valves (can be actuated)

Images COURTESY CSEM



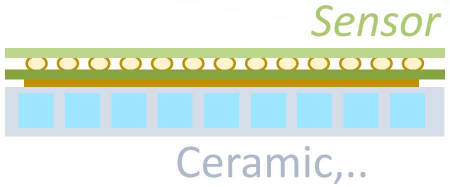
3D printed SS slender pillars

3D printed SS tube with openings (2.5 mm OD, 100 mm thick)



CERN EP-DT
3D printed ceramic cold plate

future



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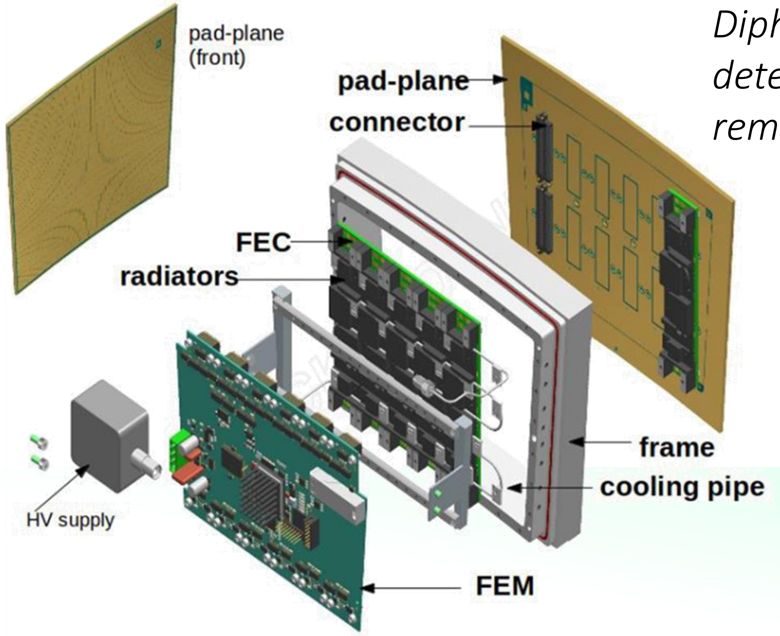
Additive manufacturing: macro-channels

CEA, Poly-shape-additive manufacturing (FR)

✓ *Detectors at future accelerators require more efficient cooling for their electronics. Diphasic CO2 allows a cooling at negative temperature as required by silicon detectors, or at room temperature as needed for TPCs. 2-phase CO2 cooling allows removing heat at nearly room temperature in a pipe at 50-60 bar*



← The present way of making cooling circuits for TPC front-end electronics at the endplate is to use stainless-steel pipes. Additive manufacturing, allows to include a serpentine in the plate in a more straightforward way.

present

R&D

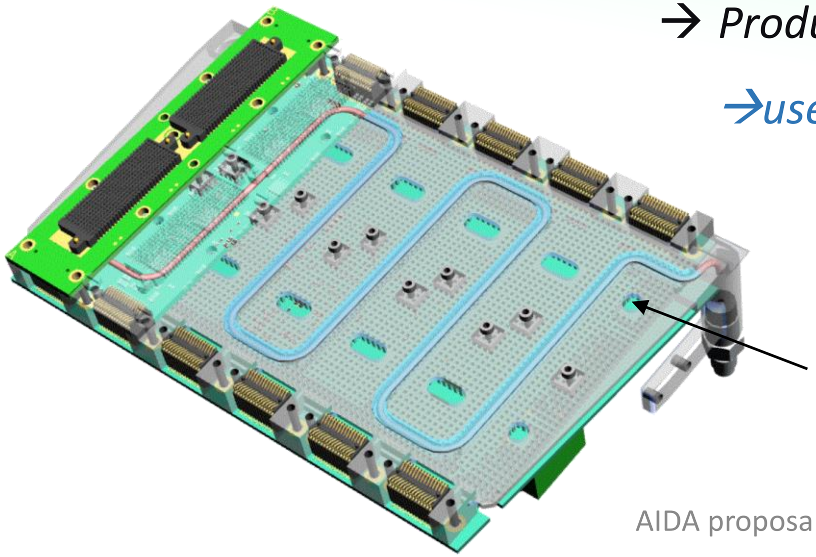
replace standard cooling pipe circuits with more integrated 3d printed circuits

→ *Investigate metal (Al) 3d printing processes*

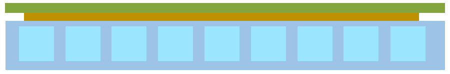
→ *Produce one piece cooling plate 3 d printed in aluminum*

→*use of AIDA test facility at the DESY test beam facility*

future



3d printed cold plate preliminary design



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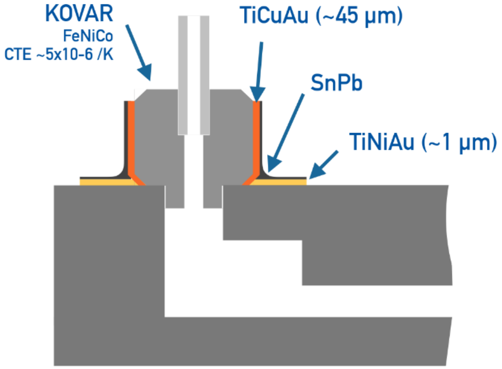
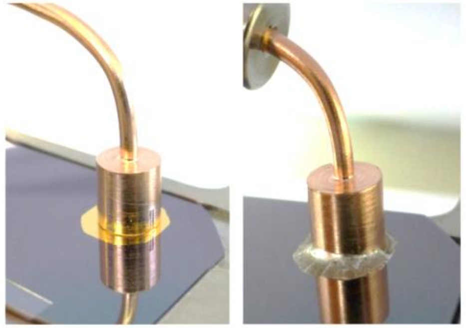
Microchannels & connectivity

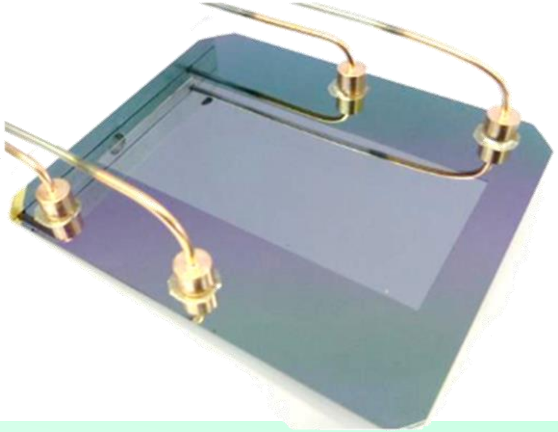
LPNHE Paris (CNRS), LAPP Annecy (CNRS), CERN, FBK-CMM

✓ *Microchannels are used in experiments such as NA62, with a forward geometry, where connectors can be placed outside the acceptance→ robust metal (Kovar) connectors→ soldered to pre-metallized silicon→ out-of-plane orientation*

present







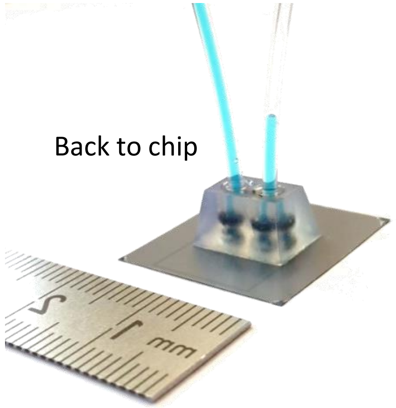
R&D

Effective microchannel connection with low mass

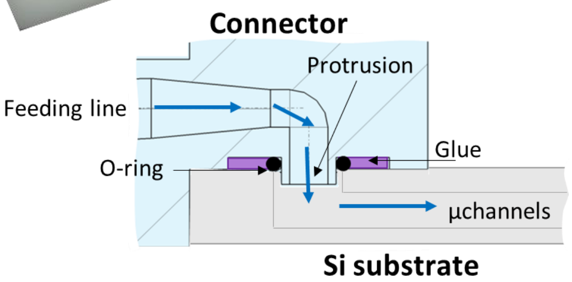
→ *Investigate additive manufacturing for lighter microchannel connectivity*
→ *Construction of a large scale cooling system to proof reliability of interconnection*
→ *Methodical study on thermo-dynamical condition along the microchannel (surface roughness, section aspect ratio)*

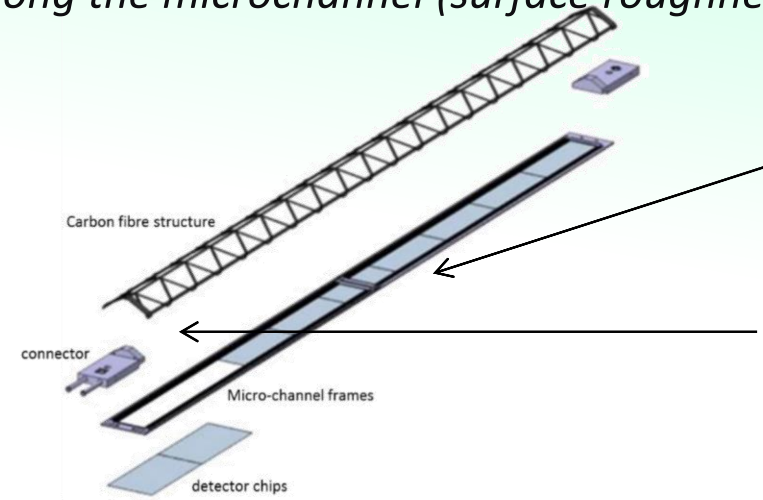
future

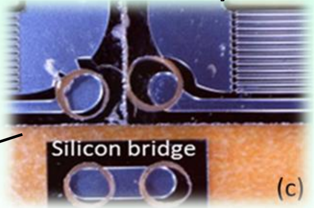
Back to chip

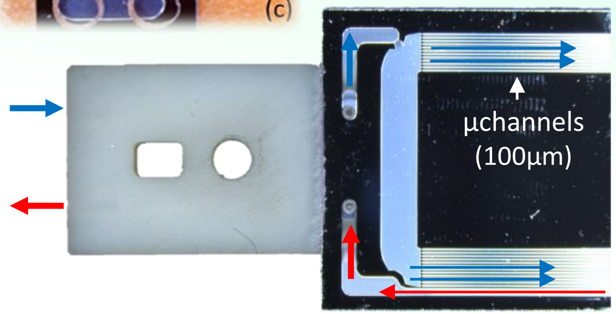


3D printed
Accura25









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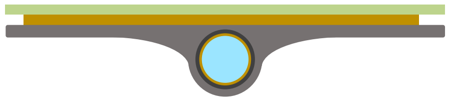
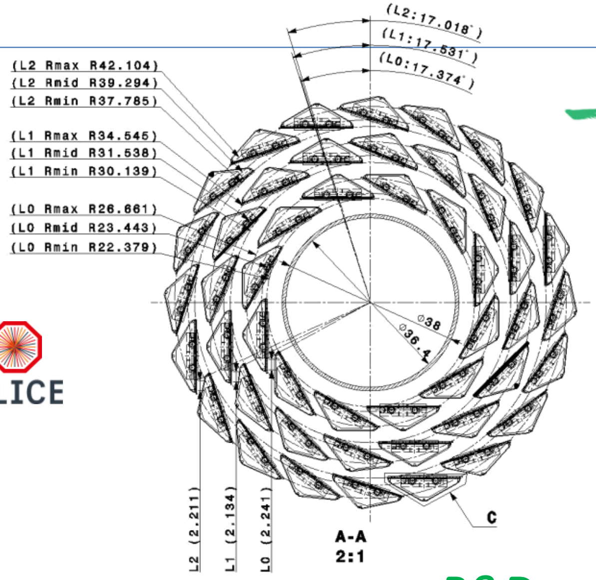
Carbon vascular



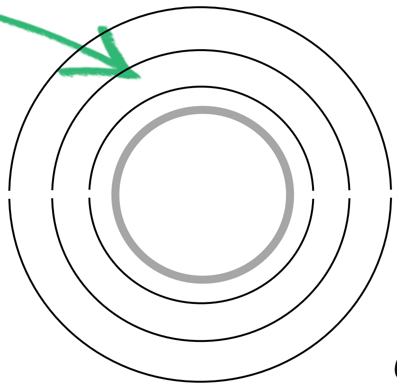
1mm kapton pipe (25um wall) available on the medical market, used in HEP

1.7 gram, tested up to 50 bar

ALICE



CERN, Workshape(FR)



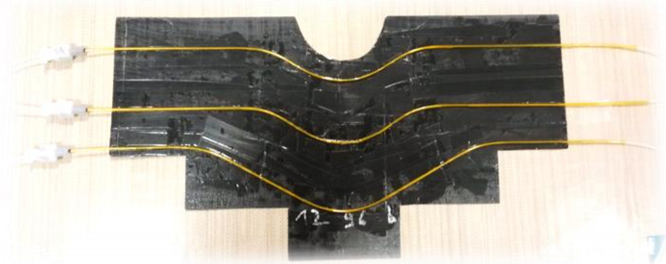
Curved Stitched Silicon sensors

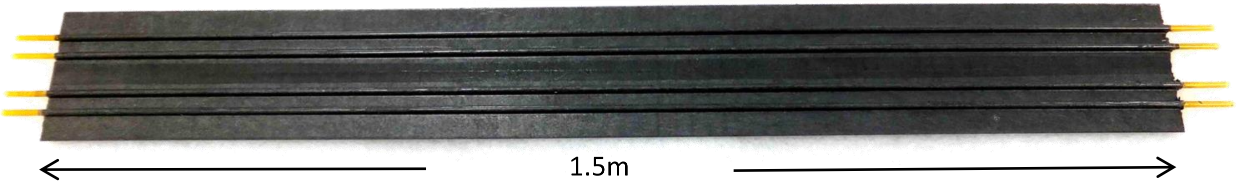
bendable silicon at thickness of about 20–40 µm
CMOS reticles alignment to produce a larger circuit

R&D

Investigate technologies limits for carbon micro-macro vascular

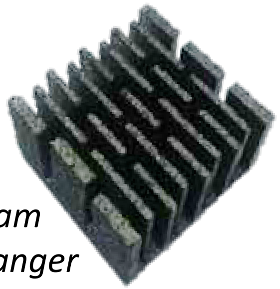
→ *Investigate smaller radius/braided pipes: higher pressure (Vertex)*
→ *Investigate longer-multiple pipes: larger surface coverage (Tracker)*
→ *Manufacture and characterize test samples*



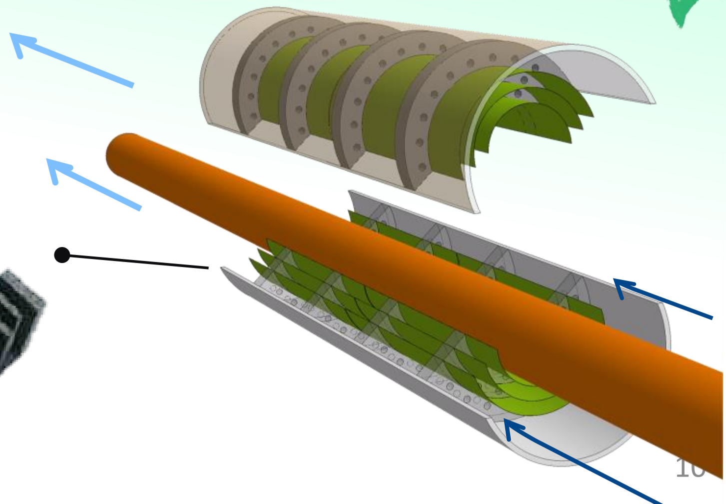


Develop ultralight carbon support/radiator for air cooling

→ *Sensors hold in place with low-density carbon foam that act as radiator for air cooling*
→ *Manufacture and characterize test samples*



Carbon foam heat exchanger



82 Coolant CO2 supercritical

present

CERN, UNIMAN, NTNU (DEPE), GE Aviation Munich (DE)

- ✓ *For **low radiation environment**, in parallel with gas cooling, **active liquid cooling** systems, operated at **room temperature**, with minimal impact on material budget, will be investigated for a more effective solution in complex or packed detector geometries.*

Carbon dioxide above the critical point (“sCO_2”) is in a peculiar phase with gas-like visco-inertial properties, but liquid-like thermo-physical properties: a **super single-phase refrigerant**

R&D

Effective coolant for ambient temperature competitive and alternative to gas cooling

→ *knowledge acquisition sCO2 behavior as ambient temperature coolant*

→ *Improvement of heat exchanger design for sC02*

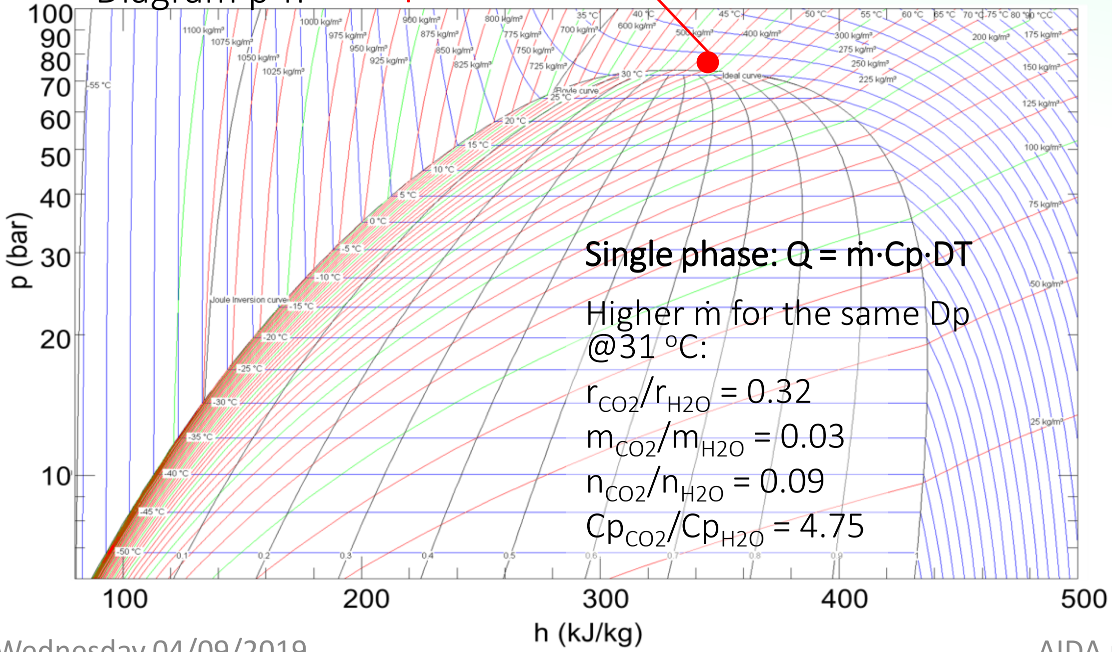
→ *Full characterization of CO2*

→ *Investigation of fluids supercritical state (also for low temperature* i.e. Kr)

future

T=31.1 °C
p=72.9 bar

Diagram p-h



Single phase: Q = ṁ·Cp·DT

Higher ṁ for the same Dp @31 °C:

$r_{CO2}/r_{H2O} = 0.32$

$m_{CO2}/m_{H2O} = 0.03$

$n_{CO2}/n_{H2O} = 0.09$

$Cp_{CO2}/Cp_{H2O} = 4.75$

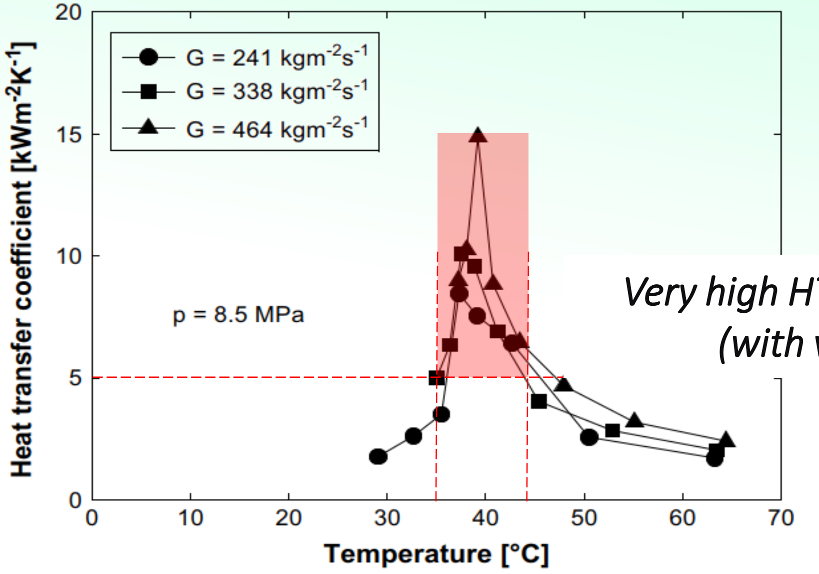


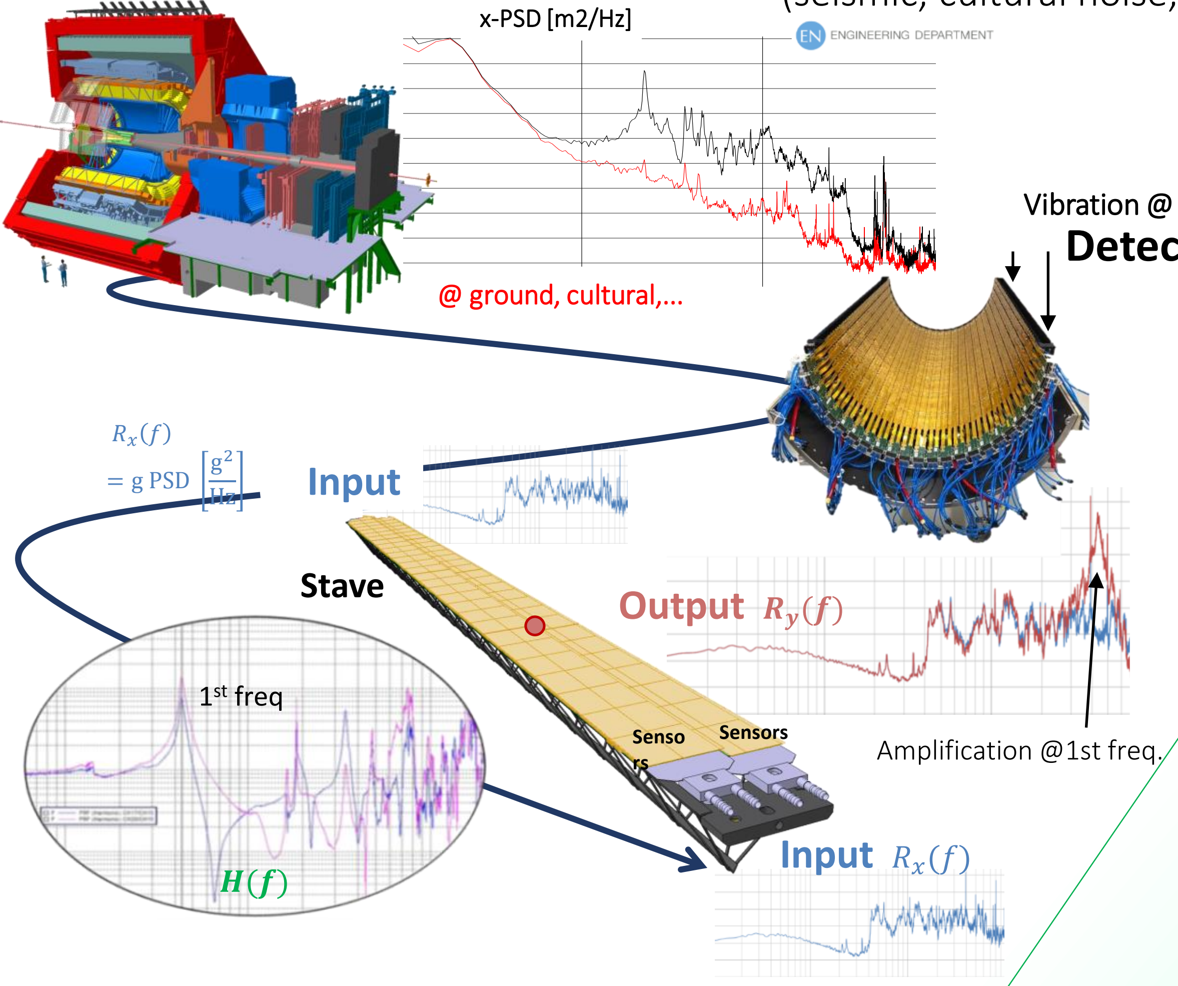
Fig. 3 – Heat transfer coefficient versus bulk temperature for different mass fluxes by Yoon et al. (2003).

Very high HTC in single-phase (with very low viscosity)

Performance verification for mechanical support structures

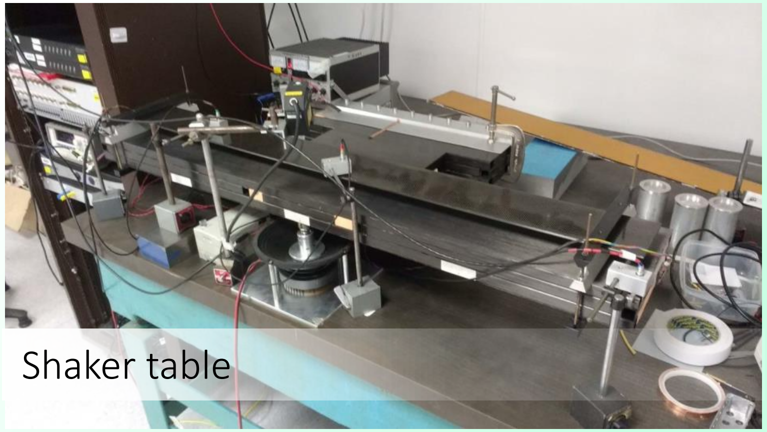
Univ of Oxford, IFIC Valencia, Univ of Bristol, Etalon GmbH (DE)

✓ Predict sensor stability in operative environment, (seismic, cultural noise, air cooling, services,...)



Ultralight
mechanical support structures

R&D



Established design criteria and test procedures for ultralight tracker mechanics

→ *Improve methodology and survey technologies (touchless probe)*
→ *Full characterization of new developed ultralight structures*
→ *Test procedure and facility available for external users*

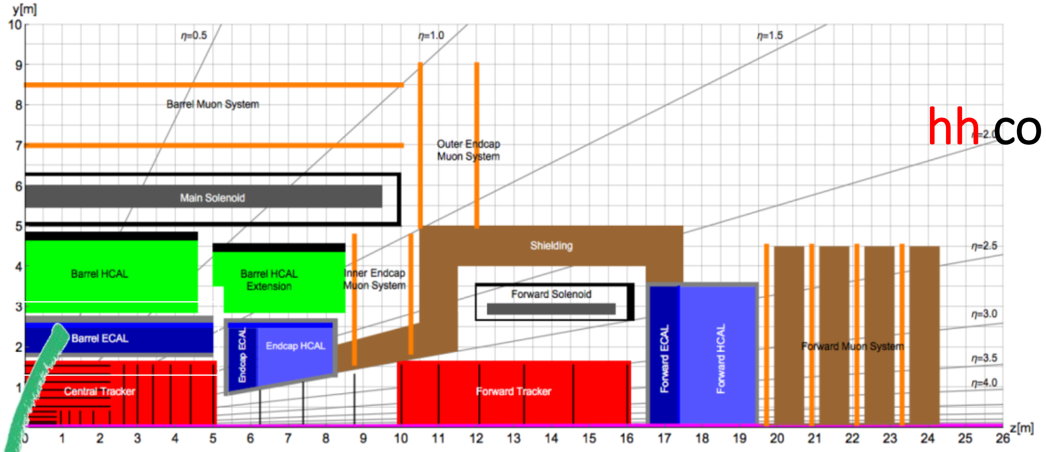
use of AIDA test facility at the University of Oxford

R02 Future detector ultra-thin cryostat

✓ *Cryostats in HEP are still the purview of metals.*

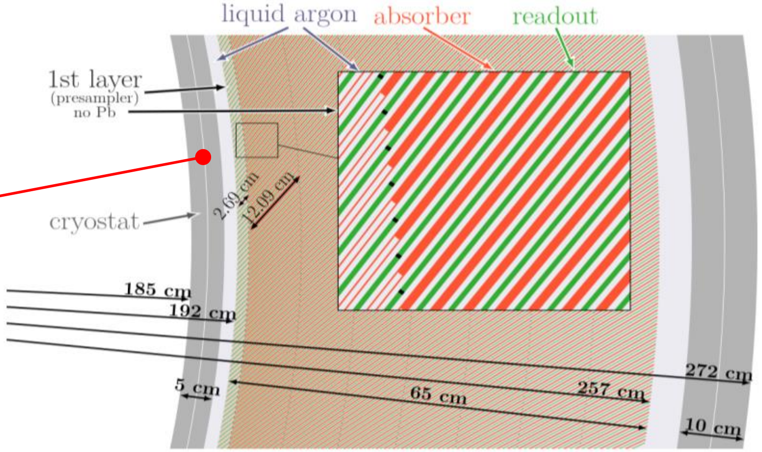
Baseline geometry, FCC-hh LAr barrel ECAL :

The aluminium cryostat is 5 cm thick, representing 56 % of X0 at η=0



hh collisions

Cryostat calorimeter (double vessel)



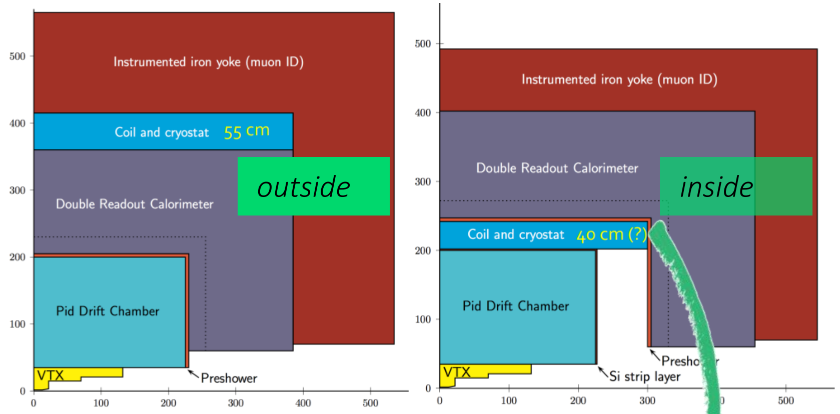
minimum material

Baseline geometry, FCC-ee :

a very challenging 2T solenoid "ultra-thin and transparent"

e^+e^- collisions

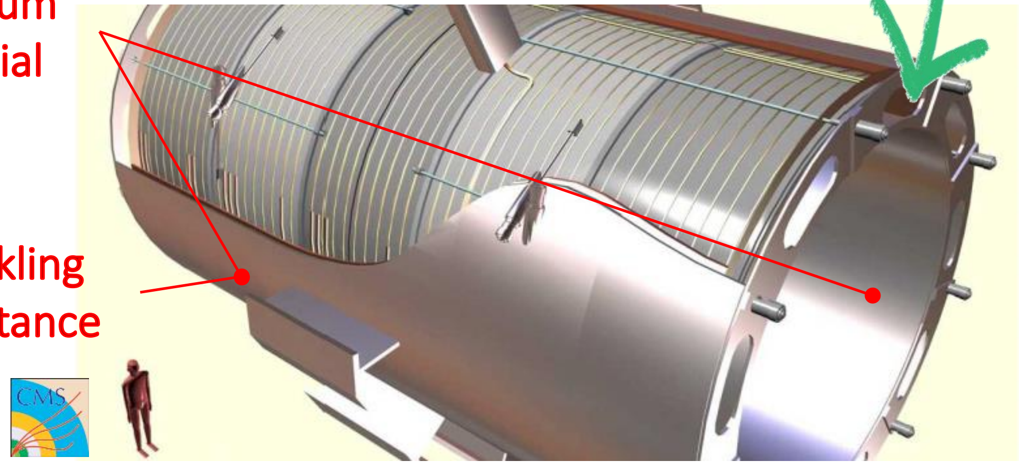
Solenoid outside or inside calorimeter



Cryostat magnet

minimum material

buckling resistance

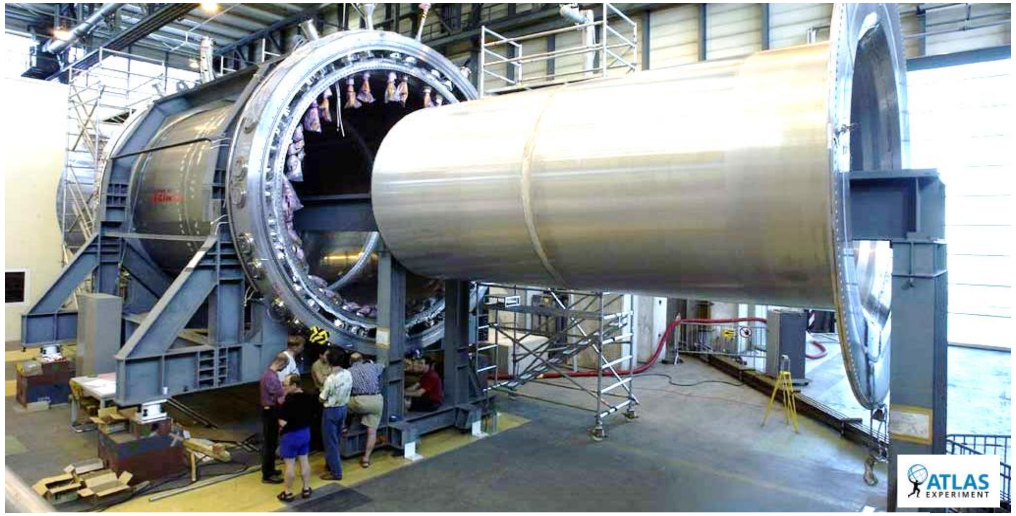


✓ Design solutions based on Carbon Fibre Reinforced Plastic will be investigated to fulfil specific HEP cryostat requirements

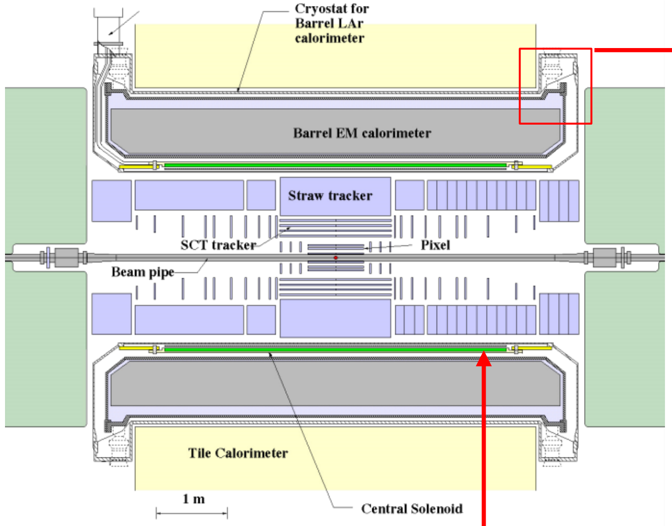
41 Carbon cryotank: **Calorimeters and Detector Magnets**

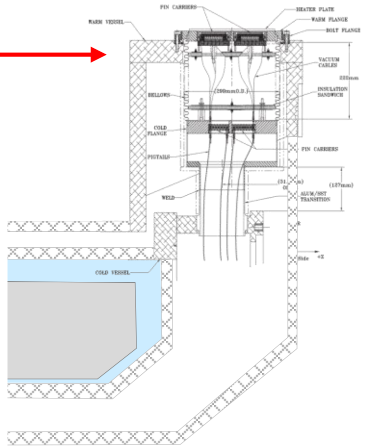
CERN, Workshape(FR)

- ✓ New detectors design aims to Ultra Lightweight (ULW) cryostats for both magnets and liquid calorimeter. Use of reinforced Plastic (CFRP) to replace Aluminum will be explored.



ATLAS Cryostat for the barrel calorimeter.

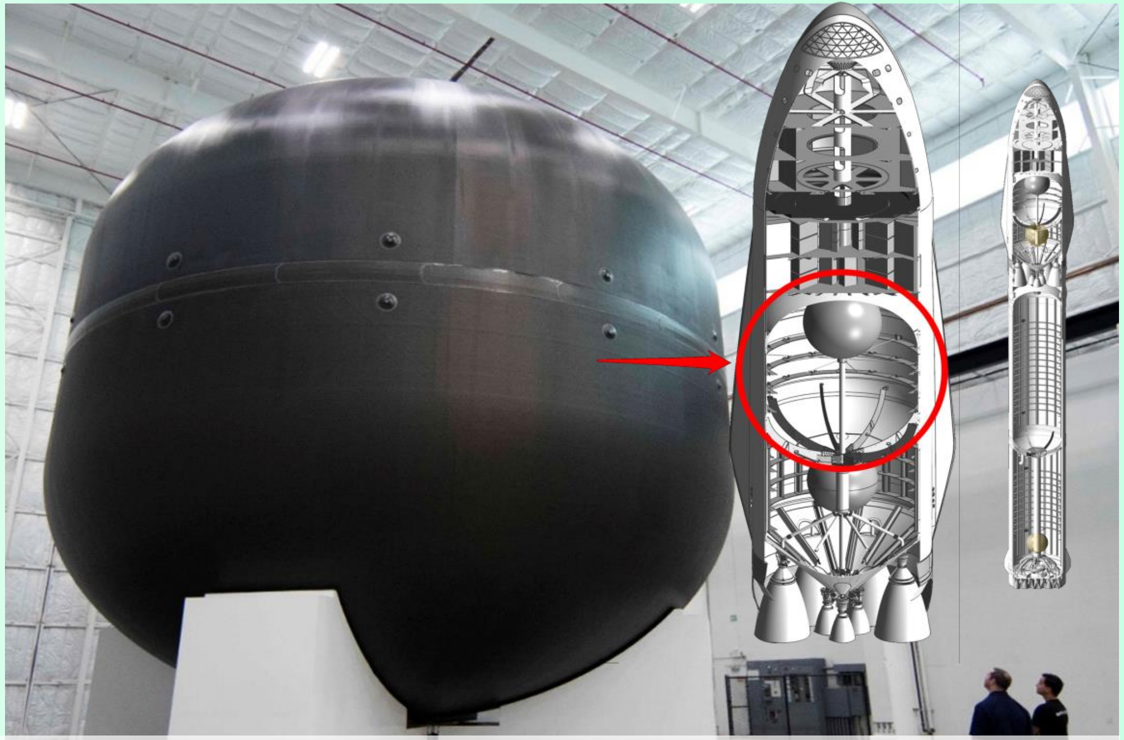




Sensitive material thickness reduction in HEP cryostat in carbon composite

- ✓ *Investigate how to tailor Carbon FRP processes and materials for HEP cryostat: fluid tightness, thermal **insulation**, feed through, radiation loads*
- ✓ *Manufacture of samples to validate process and design features*

R&D

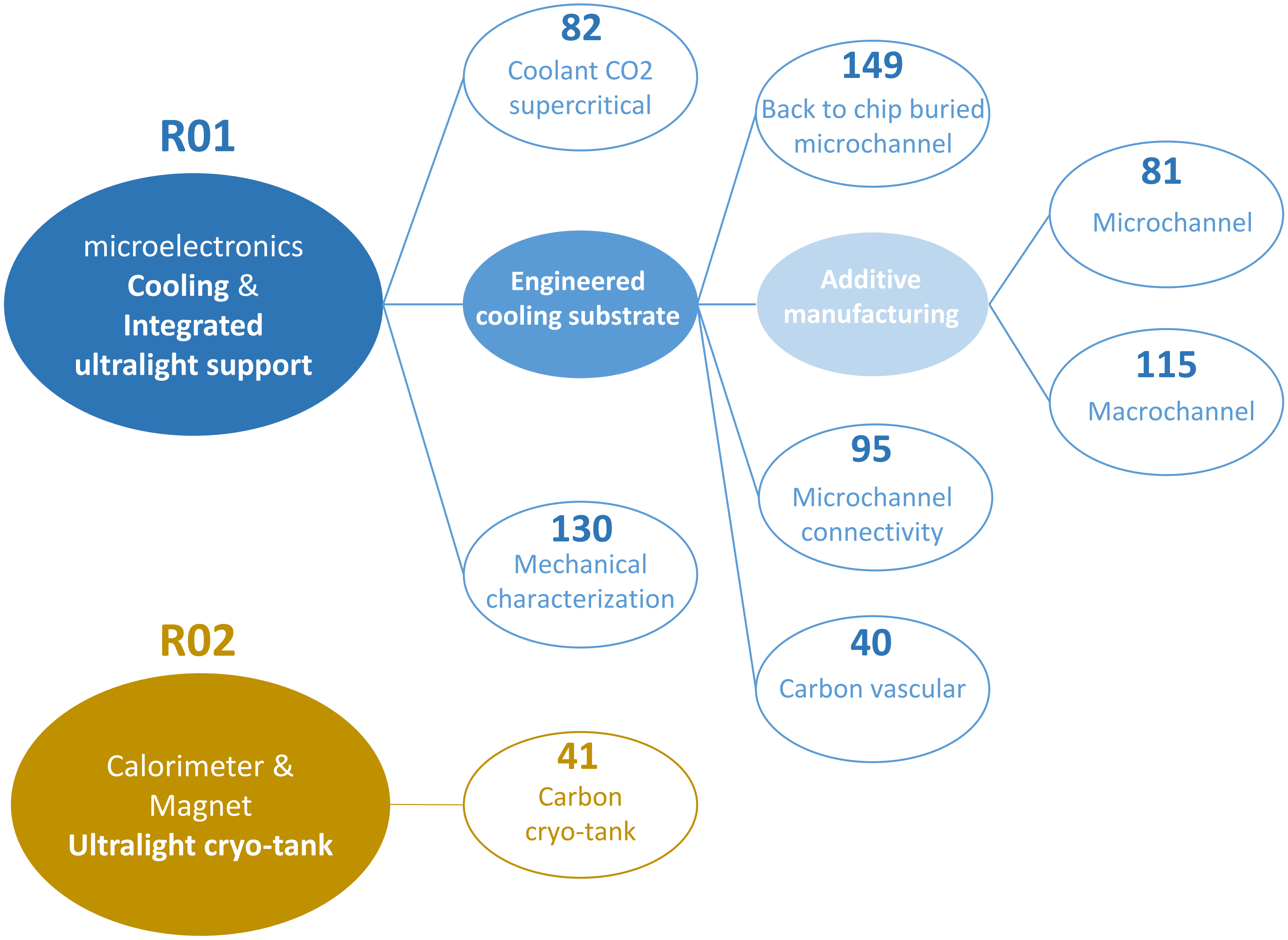


SpaceX ITS LOX tank.

The tank is made of carbon fibres. it is approximately 12 meters in diameter,

SPACEX

Summary:



Added value

149
Plug & play Chip with integrated cooling and support buried on the back of the sensor

81
Possibility to develop cheap and non planar microchannel substrate 3d printed

115
Possibility to replace standard pipe circuit with more integrated 3d printed circuit

95
Effective connection among microchannels and between microchannels and feeding lines

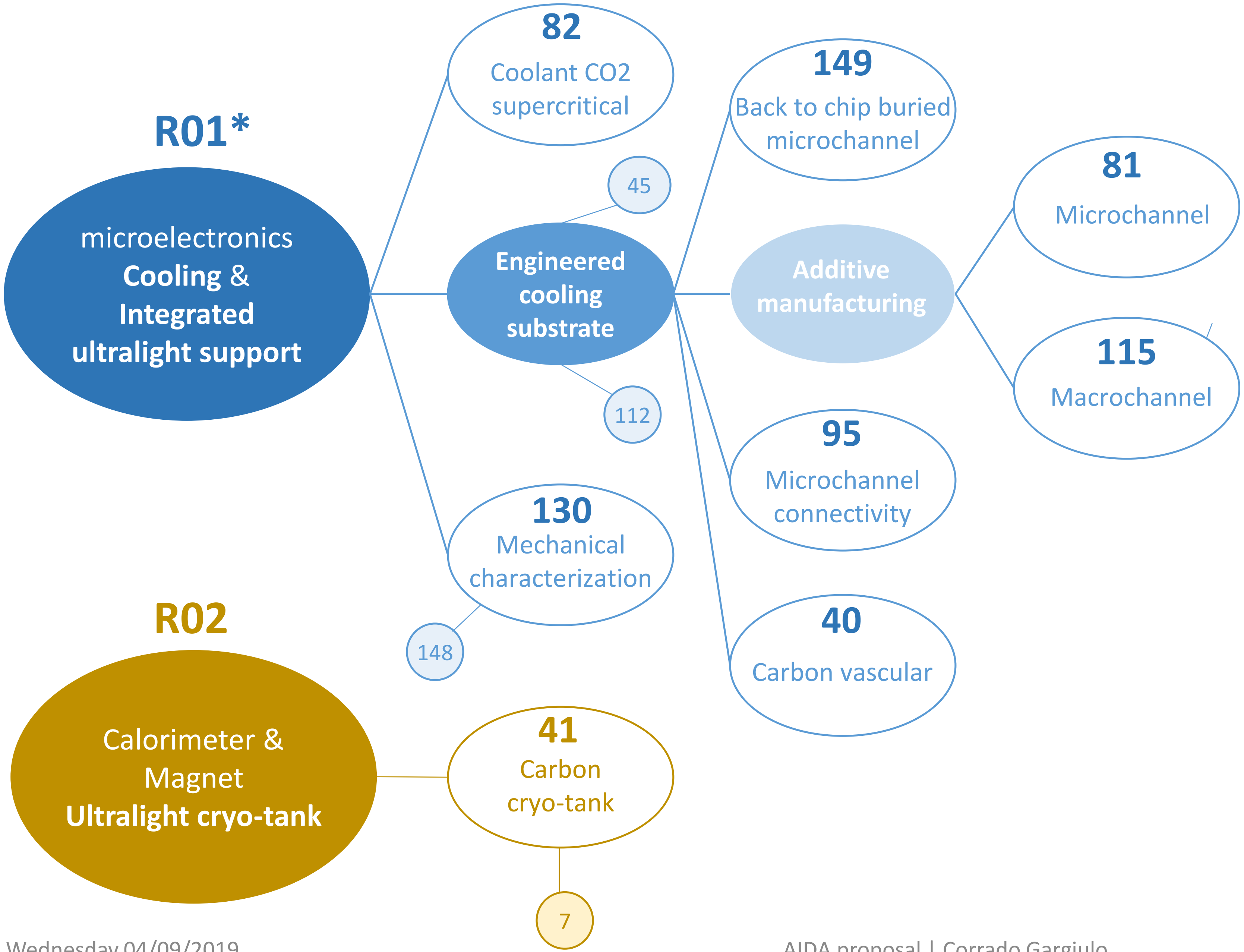
40
Unprecedented ultralight thermal/mechanical carbon heat exchanger/support

82
Effective coolant for ambient temperature competitive and alternative to gas cooling

130
Established design criteria and test procedures for ultralight tracker mechanics

41
Sensitive material thickness reduction in HEP cryostat

Summary:



Link to other **EoIs**

The Mechanics and Cooling EoIs are closely connected to several other EoIs, in particular to those looking at the development of novel sensors for future vertex and calorimeter detectors. Few references listed below.

40, 81, 95, 149

45 - Ultrathin CMOS pixel modules for precision tracking in high rate e^+e^- environment

112-Development of an ultra-thin, wafer-scale CMOS Monolithic Active Pixel Sensor in 65nm technology for applications in tracking and calorimetry

130

148-Versatile Assembly, Qualification and Measurement Framework for Complex Detectors

41

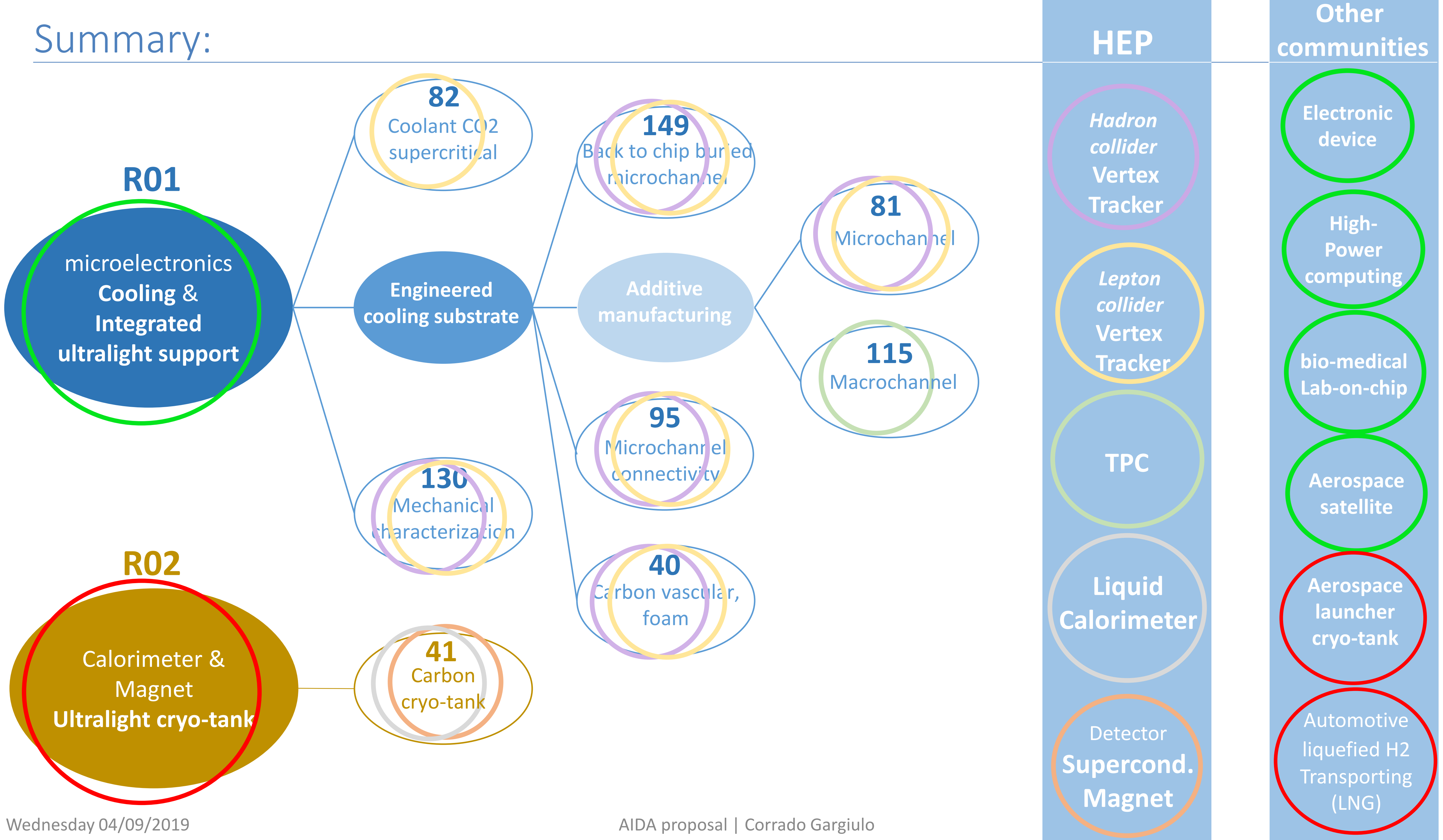
7-R&D for future high-granularity noble liquid calorimetry

** Some of the new research activities, will leverage on experimental facilities built in the frame of AIDA2020*

Possible synergies with other R&D with CERN EP R&D WP4 (Mechanics) strategic programme on Technologies for Future Experiments

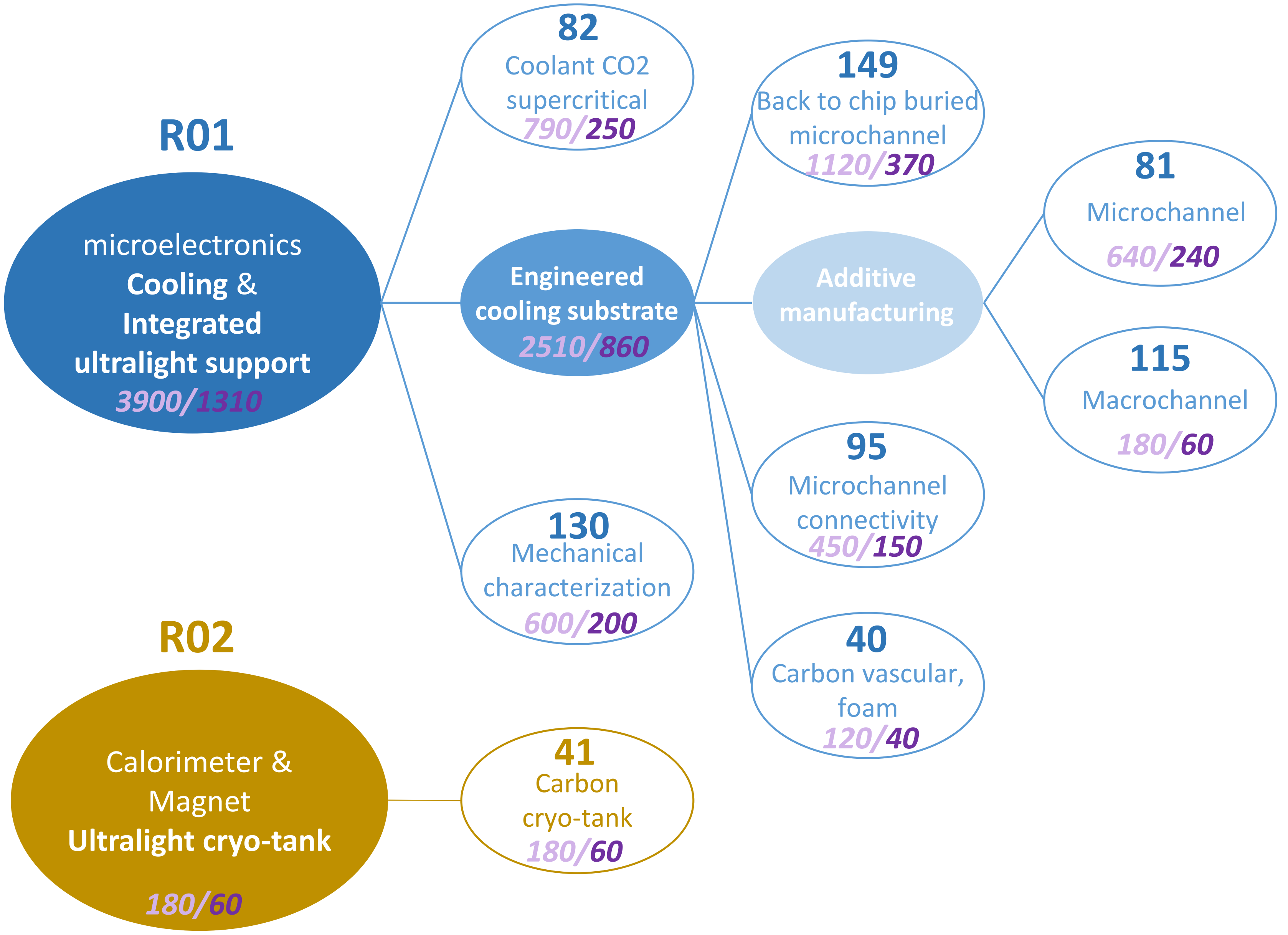
…

Summary:



R01
microelectronics
Cooling &
Integrated
ultralight support
R02
Calorimeter &
Magnet
Ultralight cryo-tank
82
Coolant CO2
supercritical
Engineered
cooling substrate
130
Mechanical
characterization
41
Carbon
cryo-tank
149
Back to chip buried
microchannel
Additive
manufacturing
95
Microchannel
connectivity
40
Carbon vascular,
foam
81
Microchannel
115
Macrochannel
HEP
Hadron
collider
Vertex
Tracker
Lepton
collider
Vertex
Tracker
TPC
Liquid
Calorimeter
Detector
Supercond.
Magnet
Other
communities
Electronic
device
High-
Power
computing
bio-medical
Lab-on-chip
Aerospace
satellite
Aerospace
launcher
cryo-tank
Automotive
liquefied H2
Transporting
(LNG)

Research Objectives (RO)



Project Cost (kEur)		EU contribution (kEur)
149 Back chip buried channel	1120	370
81 Microchannel	640	240
115 Macrochannel	180	60
95 Microchannel connectivity	450	150
40 Carbon vascular, foam	120	40
82 Coolant CO2 supercritical	790	250
130 Mechanical characterization	600	200
41 Carbon cryo-tank	180	60
	4080	1370