WP9: New support structures and micro-channel cooling

April 30th 2020

FINAL AIDA-2020 Annual Meeting
Apr 28th – 30th 2020

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654168.

Reminder: why WP9?

- Improve the **integration of ultra-light support structures and cooling devices** in the design of future detectors
- Develop the missing **building blocks** for a generalized implementation of **micro-channel cooling devices**
- Provide **common standards for the fabrication and testing** of micro-channel cooling devices

→ **T9.2: R&D targeting new technologies**

- Develop a **facility for low-mass support structure testing**, with adequate standards for characterization and validation
- Provide and validate **test structures and libraries for FEA simulations**

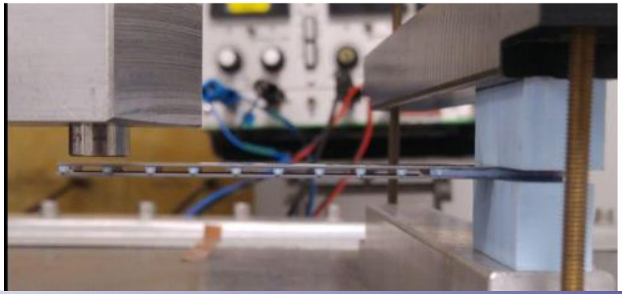
→ **T9.3: Setup of a distributed facility for future access**

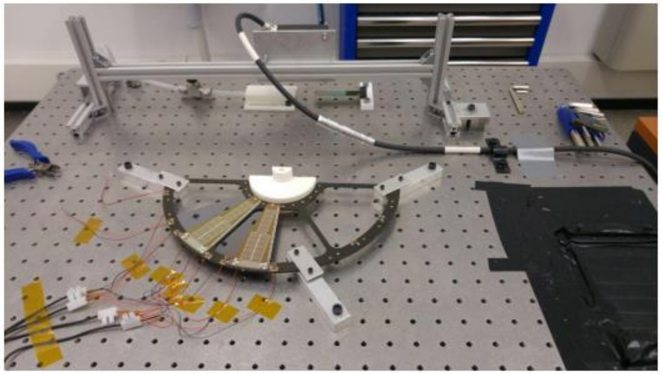
Modelling the behaviour of Silicon as the "ultimate detector support structure"

Vibration Analysis of thin Silicon Sensors

Vibration analysis of silicon sensors with multiple geometries.

Working on the understanding and characterization of vibrations induced by air cooling of simple structures to be able to design and optimize complex ones.





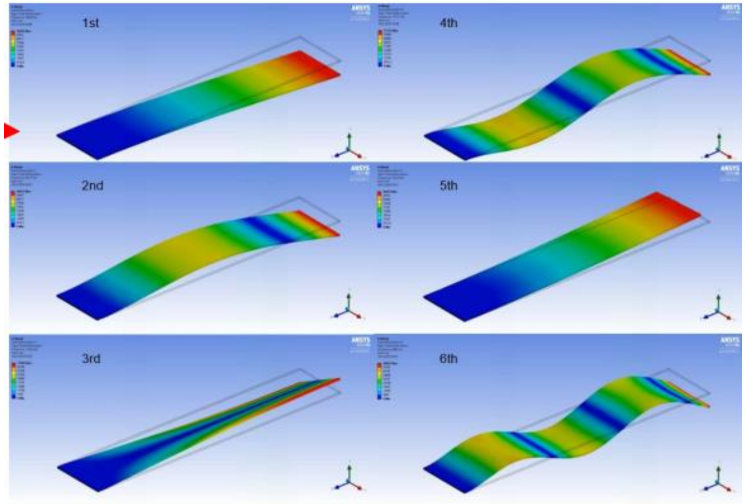
Courtesy: G. Vidal

"YEAR 5" WP9 developments

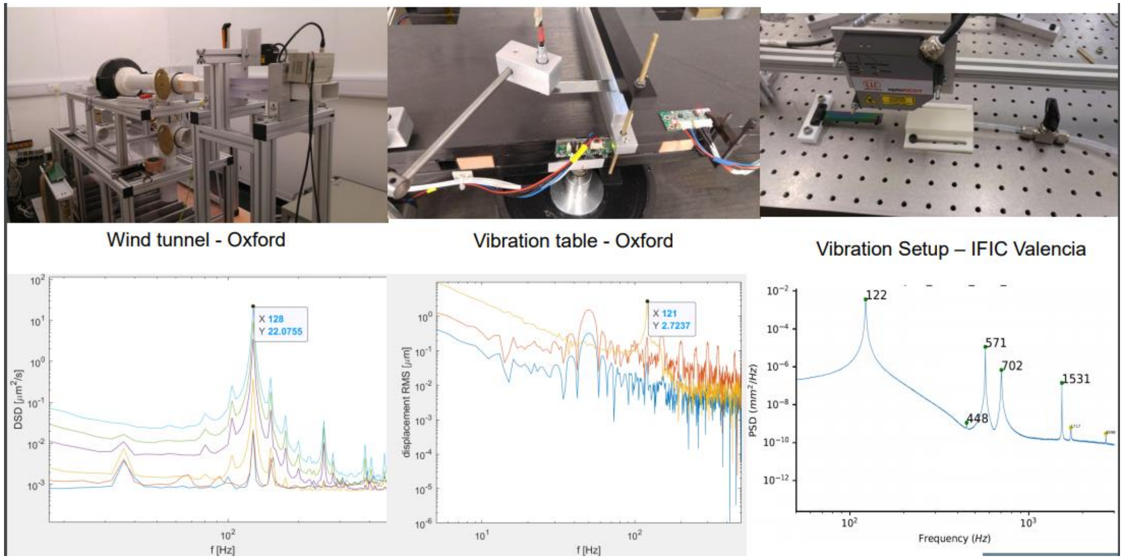
Modelling the behaviour of Silicon as the "ultimate detector support structure"

From numerical simulations…

1st to 6th Vibration modes of a Cantilever all Silicon ladder



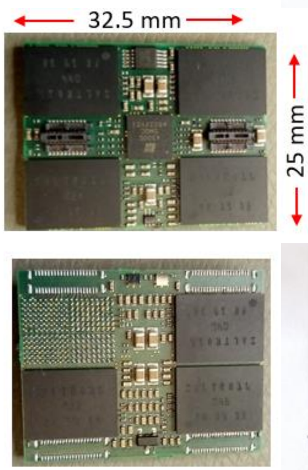
… to direct measurements on different platforms

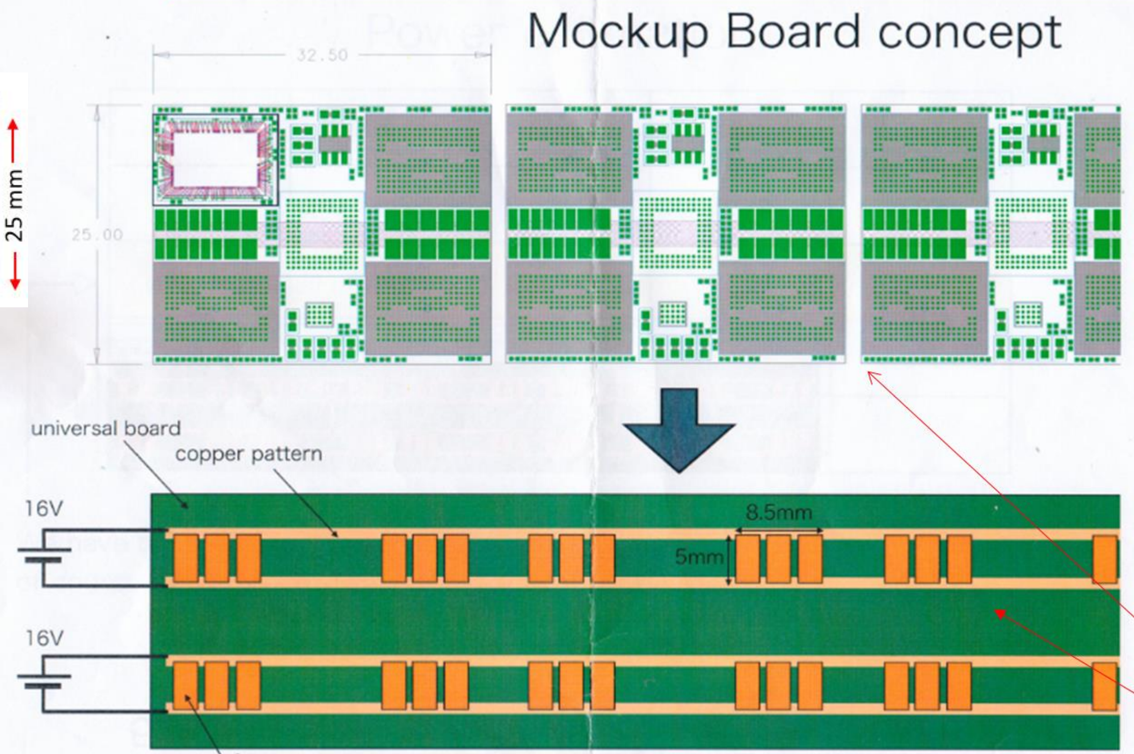


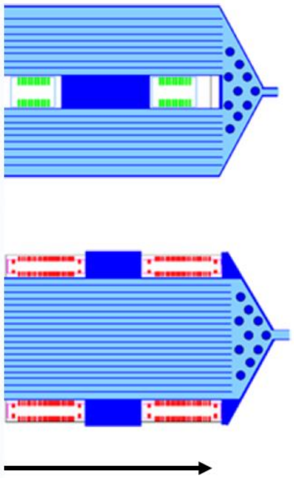
Courtesy: G. Vidal

Thermal management of a MCM board for MPGD’s with micro-pipe arrays: A common activity WP13-WP9

We propose to start a test with a ’one-ladder’ prototype. Such a prototype system is illustrated below.



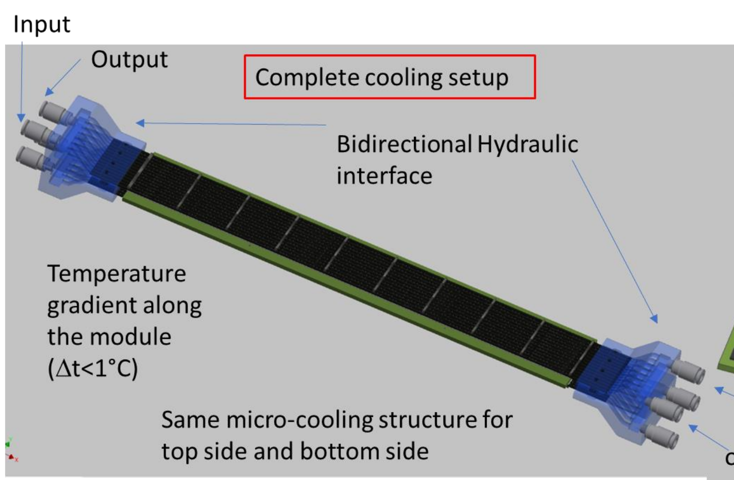


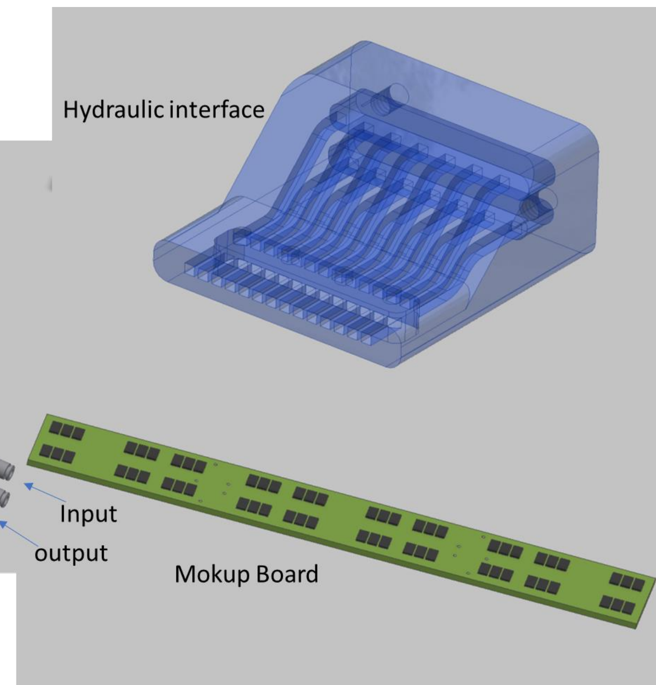


Courtesy: F. Bosi / L. Jonnson

Thermal management of a MCM board for MPGD's with micro-pipe arrays: A common activity WP13-WP9

Design completed
3D-printed PEEK connector ready
All orders being delivered
Test in summer (if COVID-19 allows…)

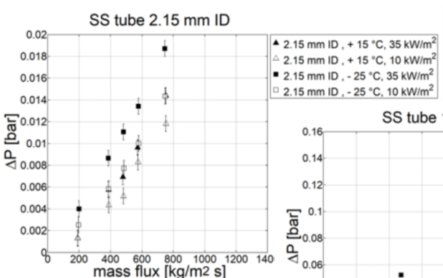


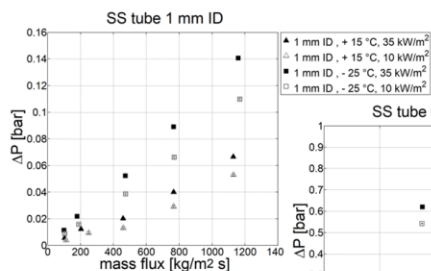


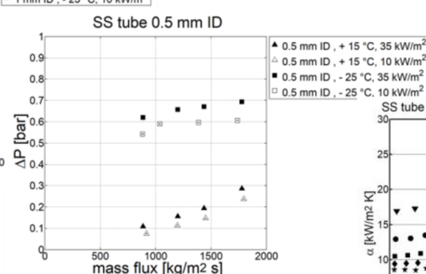
Courtesy: F. Bosi / L. Jonnson

Exploitation of the new AIDA-2020 test facility

Largest experimental database on CO_2 flows
boiling in mini- & micro-channels ever
collected: 900 DP and 10,800 HTC pts.

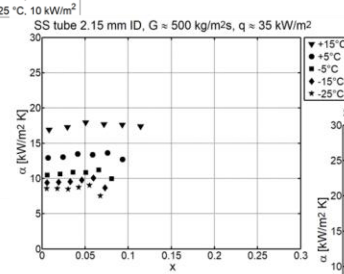


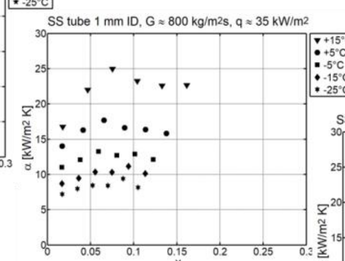




3 Inner Diameters
9 Saturation Temperatures
5 Heat Fluxes
11 Mass Fluxes

Combined effect of mass flux, heat flux and saturation temperature on pressure drop for the 3 Inner Diameters
(only Max and min are shown for heat flux and temperature)





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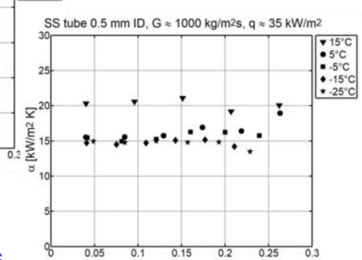


Example of the effect of the Saturation temperature on the Heat Transfer Coefficient as a function of vapour quality for the 3 Inner Diameters
(one Mass flux and Max heat flux are shown for example)

"YEAR 5" WP9 developments

Exploitation of the new AIDA-2020 test facility

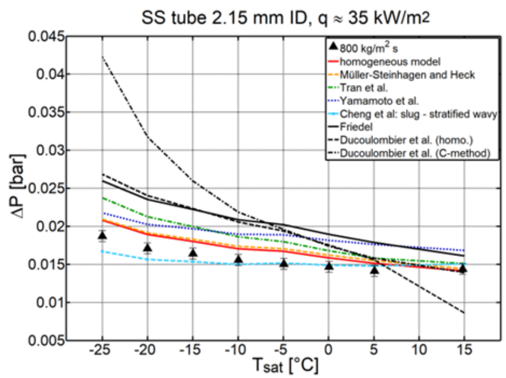
Existing boiling models tested against
reliable experimental results

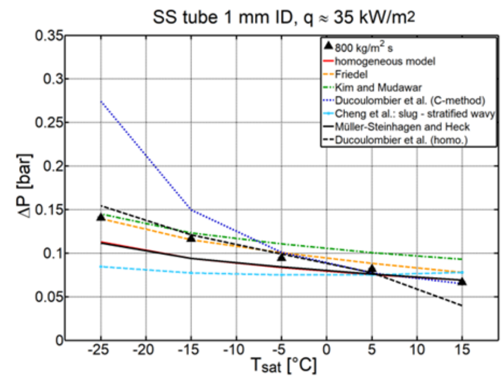
correlation (class)	2.15 mm ID tube average	2.15 mm ID tube mean	2.15 mm ID tube ξ_{20}	1 mm ID tube average	1 mm ID tube mean	1 mm ID tube ξ_{20}	0.5 mm ID tube average	0.5 mm ID tube mean	0.5 mm ID tube ξ_{20}
	Deviation [%]								
homogeneous model	-10.07	15.91	71.33	-19.92	20.14	51.35	7.34	36.81	28.33
McAdams et al. [25]	-15.20	17.56	64.87	-24.13	24.13	43.24	2.69	36.17	26.11
Beattie and Whalley [26]	-34.17	34.86	19.71	-42.30	42.30	2.70	-11.08	34.03	28.89
Cicchitti et al. [27]	-11.22	15.82	70.25	-20.74	20.84	48.65	6.33	36.51	27.78
Dukler et al. [28]	-16.71	18.67	62.72	-25.51	25.51	39.19	1.47	36.37	25.56
Akers et al. [29]	-12.50	16.30	68.10	-21.78	21.85	45.95	5.19	36.54	26.67
Lin et al. [30]	-12.73	16.27	68.46	-21.73	21.82	45.95	5.11	36.52	26.11
macro-channel correlations									
Müller-Steinhagen and Heck [31]	-10.42	16.56	69.18	-20.34	20.65	50.00	-9.50	30.47	35.00
Grönnerud [32]	-14.23	19.42	60.57	-24.23	24.64	43.24	-13.60	31.41	35.00
Friedel [33]	11.14	20.99	53.05	-3.14	12.75	79.73	6.55	32.84	32.22
Lockhart-Martinelli: C-method [34],[35]	62.03	69.42	27.24	66.53	72.60	18.92	117.15	125.65	12.78
Lockhart-Martinelli: B-method [36]	122.00	123.33	22.58	10.65	22.79	56.76	0.23	29.61	34.44
micro-channel correlations									
Mishima and Hibiki [37]	-30.83	31.16	29.75	-40.90	40.90	10.81	-38.28	39.68	35.00
Tran et al. [38]	-4.11	16.48	74.19	19.18	25.35	41.89	116.28	117.97	7.78
Zhang and Webb [39]	-14.51	18.26	66.31	-18.87	18.87	58.11	-10.10	27.09	40.00
Qu and Mudawar [40]	-30.79	31.11	29.75	-40.80	40.80	10.81	-38.14	39.56	35.00
Lee and Garimella [41]	-29.87	30.22	34.41	-40.48	40.48	10.81	-38.08	39.52	35.56
Lee and Lee [42]	16.34	24.65	48.39	7.44	23.15	52.70	21.10	49.13	22.22
Kim and Mudawar [43]	28.59	33.40	28.67	6.73	17.16	63.51	12.26	38.85	26.67
CO_2 correlations									
Yamamoto et al. [24]	-0.34	17.40	69.18	-7.92	19.32	55.41	2.81	37.57	26.67
Yun and Kim [21]	-30.00	30.92	30.11	-37.24	37.24	20.27	-32.61	36.85	36.11
Ducoulombier et al. (homo.) [9]	2.93	20.96	56.27	-14.98	18.36	74.32	15.51	31.51	30.56
Ducoulombier et al. (C-method) [9]	18.15	28.24	53.05	9.56	20.78	74.32	16.49	28.97	38.89
phenomenological model [44]									
Cheng et al. annular	7.00	32.93	44.09	-15.80	35.52	28.38	-2.65	46.35	22.78
Cheng et al. slug - intermittent	2.68	32.13	46.95	-23.46	30.80	32.43	-11.51	38.61	28.33
Cheng et al. stratified - wavy	20.34	38.21	40.14	-3.07	37.52	28.38	12.44	53.04	20.00
Cheng et al. slug - stratified wavy	10.61	35.55	48.75	-17.32	30.22	35.14	-3.02	41.13	25.56
Cheng et al. stratified	-18.02	25.09	43.01	-35.38	35.92	24.32	-29.78	39.59	28.33

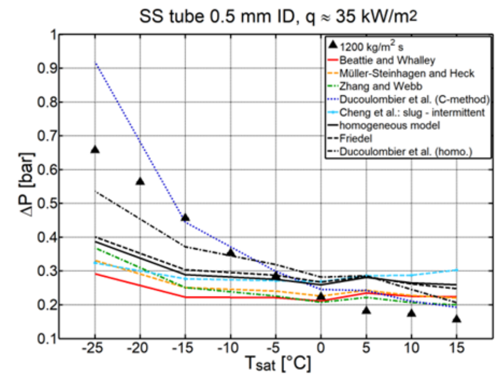
	2.15 mm ID tube average	2.15 mm ID tube mean	2.15 mm ID tube ξ_{20}	1 mm ID tube average	1 mm ID tube mean	1 mm ID tube ξ_{20}	0.5 mm ID tube average	0.5 mm ID tube mean	0.5 mm ID tube ξ_{20}
	Deviation [%]								
macro-channel correlations									
Chen []	-65.43	66.59	4.18	-23.45	43.95	21.78	-4.51	31.66	39.07
Shah []	-18.16	24.78	48.04	25.31	35.60	41.11	25.51	27.94	52.50
Kandlikar []	-14.82	18.47	56.30	21.04	28.76	47.78	25.75	27.41	40.83
Steiner & Taborek []	109.48	109.48	0.00	187.22	187.22	0.00	208.02	208.02	0.00
Liu & Winterton []	1.32	9.52	90.53	27.61	33.42	51.33	30.39	33.09	52.69
Gungor & Winterton []	31.15	48.37	38.52	27.35	33.03	48.67	34.61	36.87	41.02
Cooper []	12.40	14.61	68.20	8.69	11.13	82.89	-13.48	20.51	43.15
Wattelet et al. []	18.14	19.23	56.46	38.69	39.56	36.00	40.19	41.29	34.54
micro-channel correlations									
Warrier et al. []	25.09	66.58	22.17	160.16	165.88	14.44	164.53	165.34	6.57
Lazarek & Black []	-8.16	15.24	70.90	11.86	21.14	52.89	6.49	15.86	70.09
Tran et al. []	-16.40	22.33	46.93	-35.42	35.59	9.56	-58.46	58.46	1.76
Agostini & Bontemps []	-22.59	26.00	43.97	-39.82	40.87	19.78	-63.43	63.43	0.00
Li & Wu []	50.18	51.32	28.62	40.23	49.03	29.78	-9.28	21.25	48.15
Bertsch et al. []	-12.78	25.98	42.75	4.30	26.61	48.89	-15.54	25.17	41.20
Yu et al. []	49.88	49.88	6.72	19.96	20.22	56.89	-24.11	26.73	28.98
Kandlikar & Balasubramanian []	-22.79	28.00	50.90	14.29	27.01	48.00	11.91	19.75	63.15
Kew & Cornwell []	-7.28	14.87	72.01	12.64	21.46	53.11	7.84	16.74	66.76
Oh & Son []	-90.35	90.35	0.00	-75.41	75.41	0.22	-56.23	56.65	5.28
Kim & Mudawar []	11.57	16.65	66.24	38.99	39.00	10.67	41.17	41.57	25.09
CO2 correlations									
Ducoulombier et al. []	26.01	26.06	27.04	28.99	30.04	43.33	22.47	29.10	55.09
Yoon et al. []	37.14	37.47	27.99	113.86	114.03	11.11	133.87	133.87	0.56
Hihara & Tanaka []: Duc II	-15.74	24.94	44.13	-16.40	21.89	51.56	-15.79	22.60	49.44
Yun et al. []	3.39	14.36	70.00	-1.99	9.59	90.22	-19.30	24.82	36.30
Choi et al. []	16.94	20.10	61.38	36.05	38.02	40.22	35.22	36.33	38.52
Wang et al. []	105.50	105.50	0.11	68.64	68.64	5.33	-2.23	28.02	40.00
Pamitran et al. []	-69.96	71.05	3.92	-32.68	50.81	16.22	-27.04	44.14	16.85
Oh et al. []	-1.58	25.67	45.87	37.87	46.76	37.33	26.61	32.28	52.59
Chen et al. []: Duc I	24.59	24.63	30.32	22.43	23.49	46.00	-6.19	13.45	77.41
Duc III []	-63.29	64.83	5.24	-15.85	43.98	22.67	4.77	33.43	40.74
phenomenological model []									
Cheng et al.: annular, intermittent & bubbly	24.63	24.67	31.53	33.39	34.52	35.33	27.10	29.71	52.13
Cheng et al.: fully stratisfied	17.87	18.10	64.71	25.32	27.88	48.22	17.20	22.51	66.67
Cheng et al.: stratified - wavy	21.74	21.79	47.46	27.10	29.51	45.33	15.28	21.32	71.67
Fang et al. []	-2.89	4.28	100.00	0.16	3.95	80.00	16.97	17.06	70.83

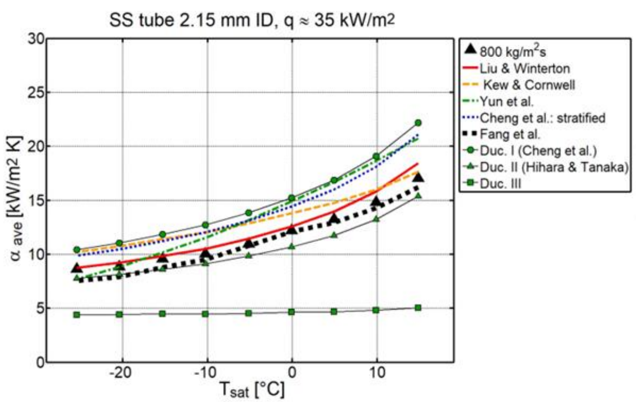
Exploitation of the new AIDA-2020 test facility

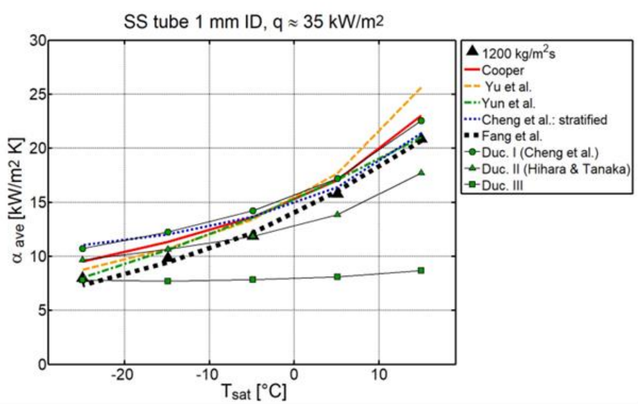
Existing boiling models tested against
reliable experimental results

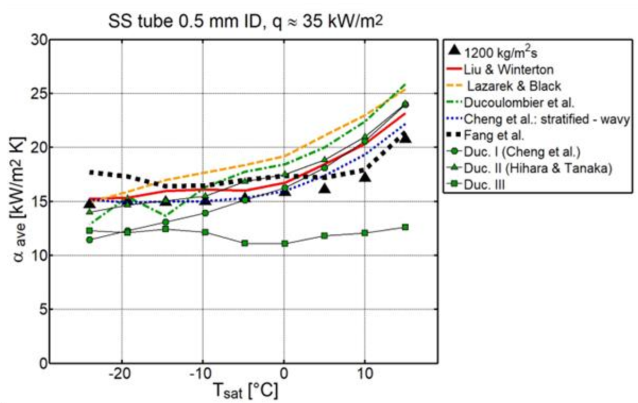




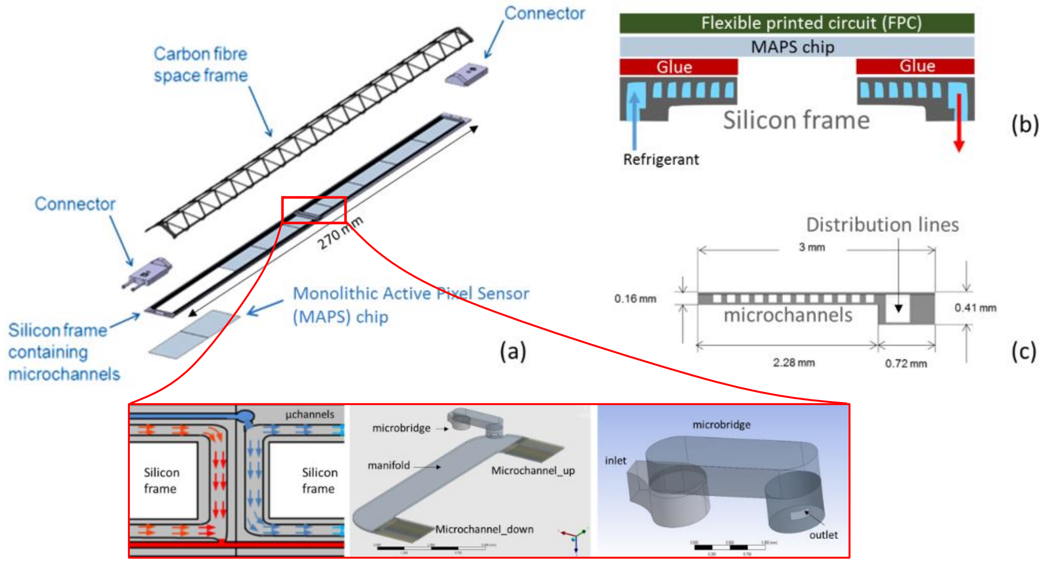




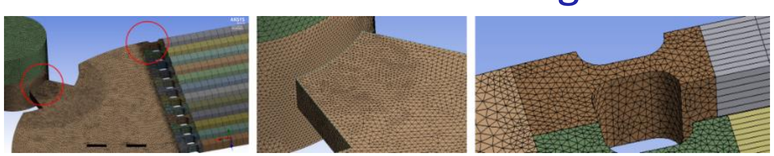




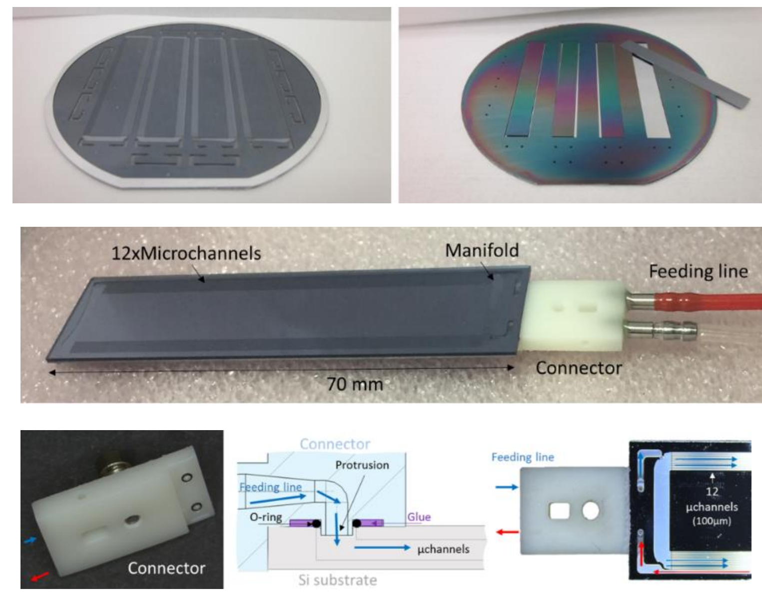
Complete treatment of a case-study (pressure drop reduction)



Numerical modelling



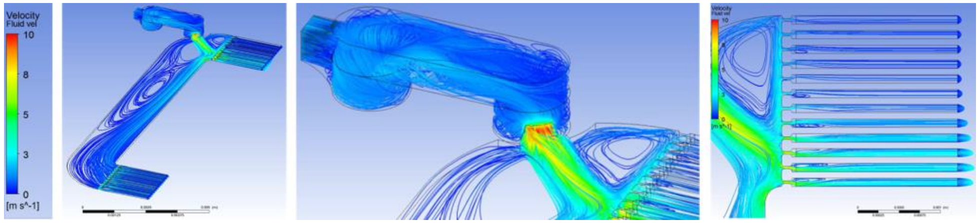
Prototype micro-fabrication



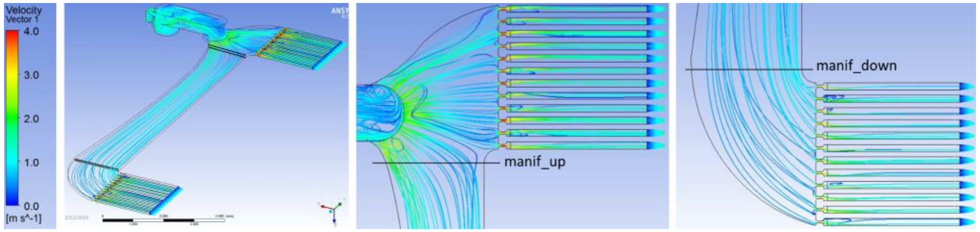
Courtesy: M. Angeletti / C. Rossi

Complete treatment of a case-study (pressure drop reduction)

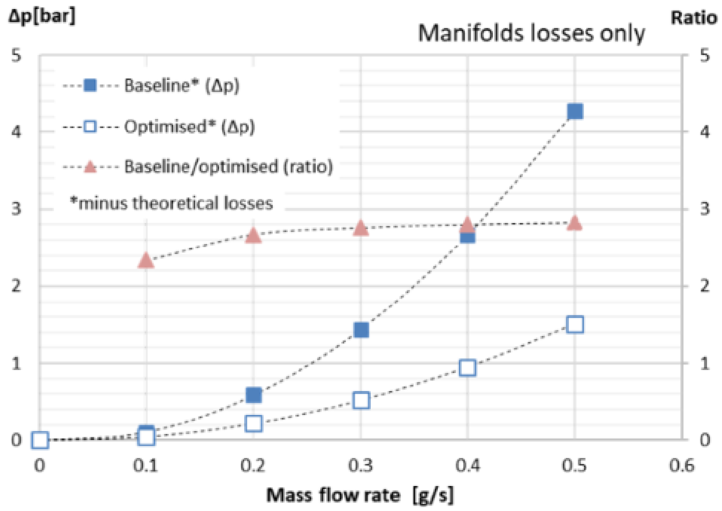
Initial Geometry



Optimized Geometry



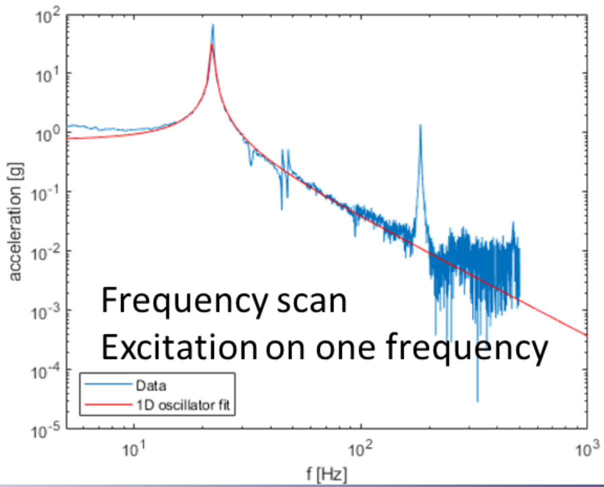
Pressure drop gain

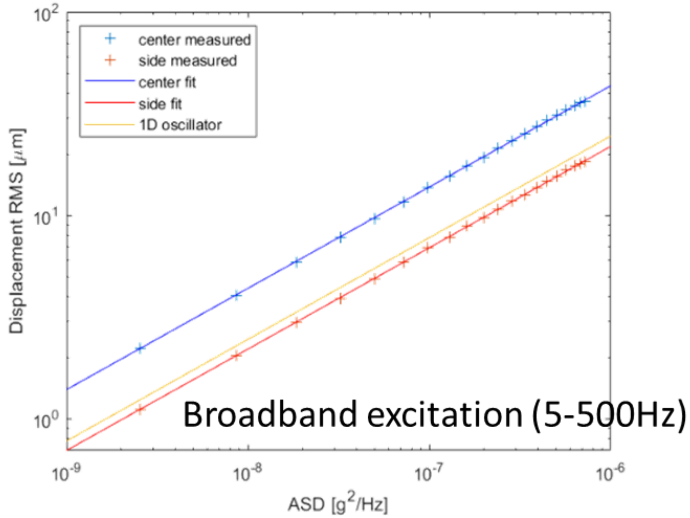


Courtesy: M. Angeletti / C. Rossi

Enhanced measurement performance of the Oxford vibration table

- **Continuing studies using vibration table**
  - We measure displacement of the device under test from a steel base table
  - The vibration table is mounted on this table and moves with respect to that
    - The device under test is mounted on the vibration table and moves with respect to both
  - We are now subtracting displacement of vibration table from displacement of device under test
  - This allows for a better comparison with simple 1D theory
  - And it removes table distortions effects.



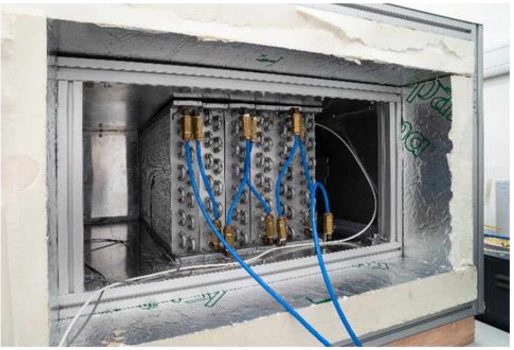


Courtesy: G. Viehhauser

"YEAR 5" WP9 developments

Enhanced air flow setup and new low-mass retroflectors for FSI

- **Other continuing activities**
  - Put on hold by Covid, but we will continue after that (even though AIDA2020 is officially over)
  - Air flow setup
    - Built a new HEX to allow for chilled air flow
    - Have started to run, but no systematic studies yet



  - Studying new low-mass retroreflectors for FSI
    - n=2 glass spheres, 1mm diameter
    - First look is promising
- **These activities will be useful if we continue in AIDAnova, but do not depend on that**
  - We are still interested in users visiting with devices they like to test

Courtesy: G. Viehhauser

FINAL DELIVERABLES

Grant Agreement No: 654168

AIDA-2020

Advanced European Infrastructures for Detectors at Accelerators
Horizon 2020 Research Infrastructures project AIDA-2020

DELIVERABLE REPORT

TECHNOLOGY RECOMMENDATIONS FOR MICRO-CHANNEL COOLING

DELIVERABLE: D9.3

Grant Agreement No: 654168

AIDA-2020

Advanced European Infrastructures for Detectors at Accelerators
Horizon 2020 Research Infrastructures project AIDA-2020

DELIVERABLE REPORT

QUALIFICATION AND CHARACTERIZATION OF MICRO-CHANNEL COOLING

DELIVERABLE: D9.4

Grant Agreement No: 654168

AIDA-2020

Advanced European Infrastructures for Detectors at Accelerators
Horizon 2020 Research Infrastructures project AIDA-2020

DELIVERABLE REPORT

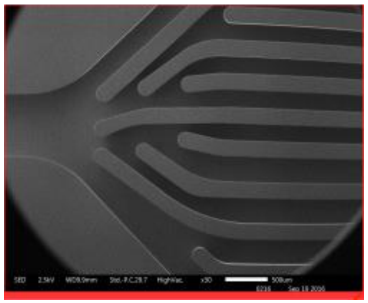
STANDARD PROCEDURES FOR CHARACTERIZATION AND QUALIFICATION

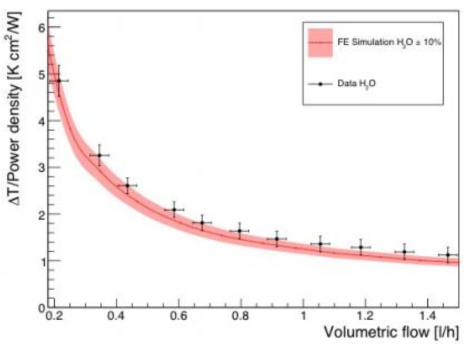
DELIVERABLE: D9.7

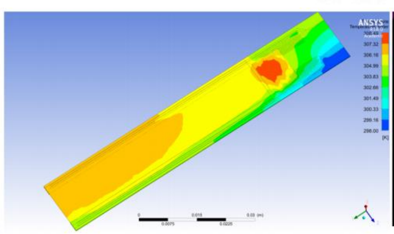
2015-2020: Achievements

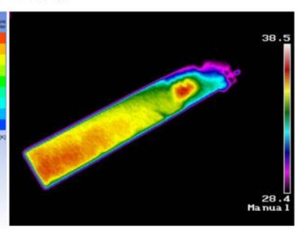
Silicon micro-channel device performance

Single-phase

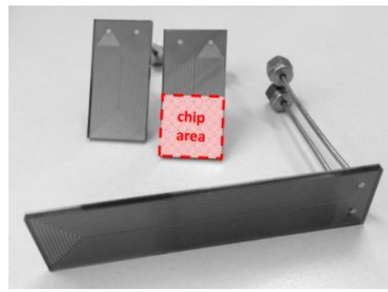


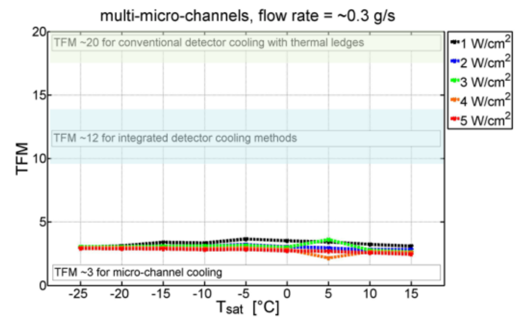


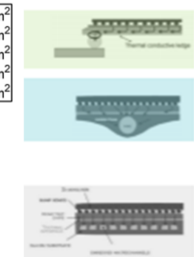


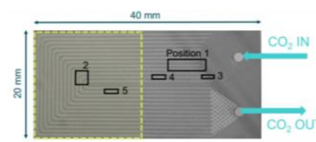


Two-phase



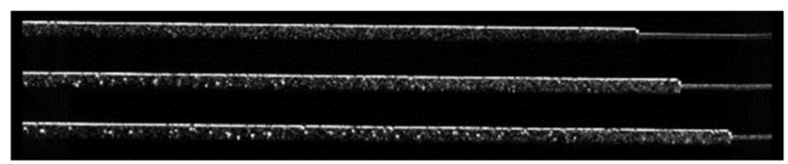


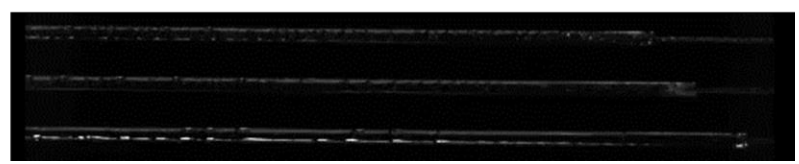




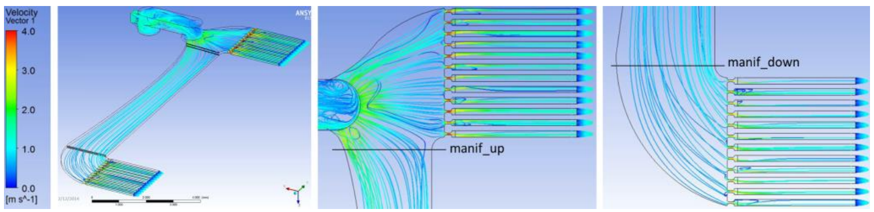
Position 1
Images: 13 600 fps
Flow rate = 0.3 g/s
Chip power = 3 W/cm²

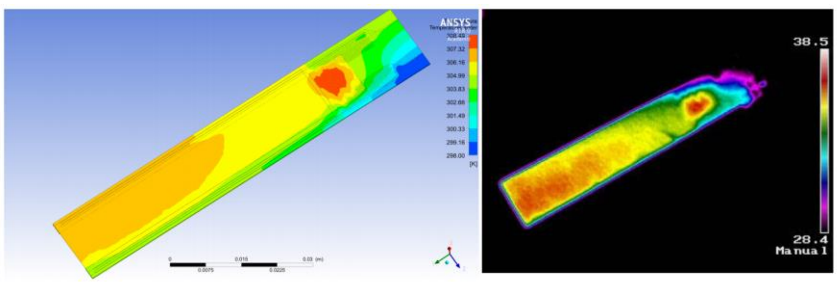
TOP: T = + 15 °C
BOT: T = - 25 °C

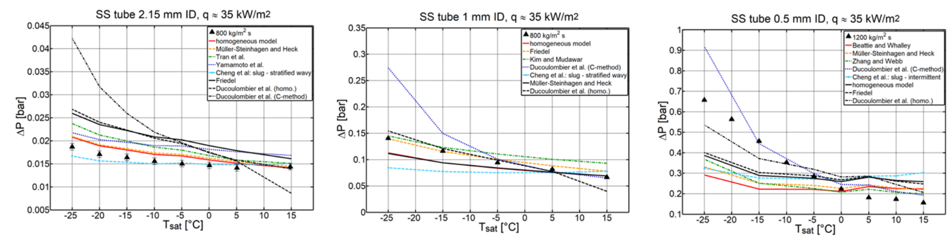


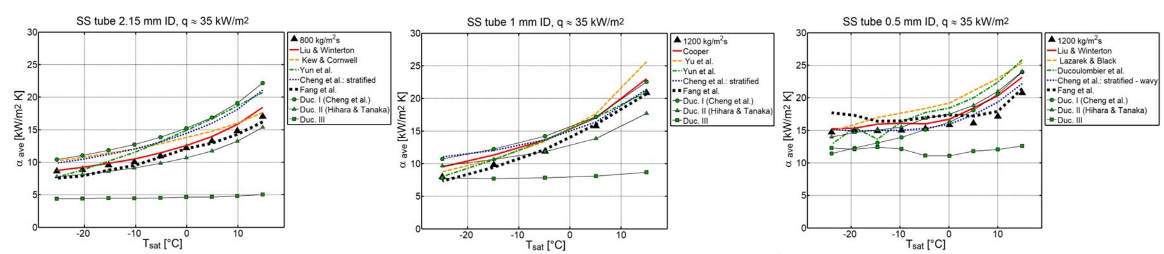


Single- and two-phase flow modelling in micro-channels

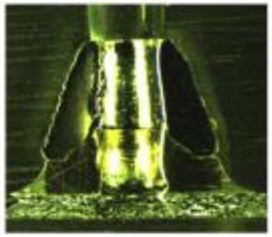


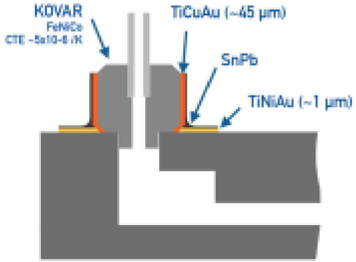


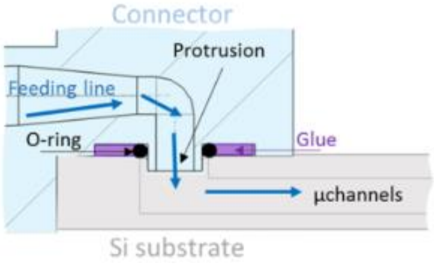


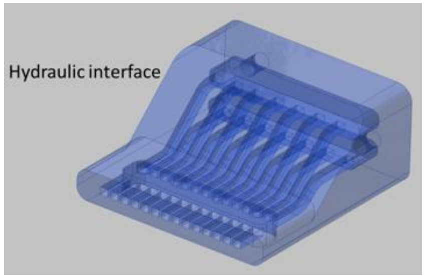


Hydraulic micro-connection technologies



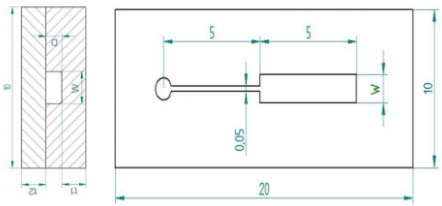


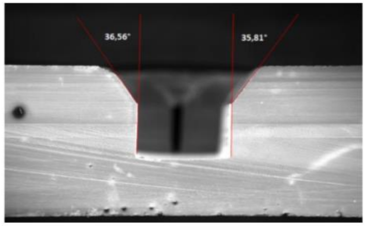


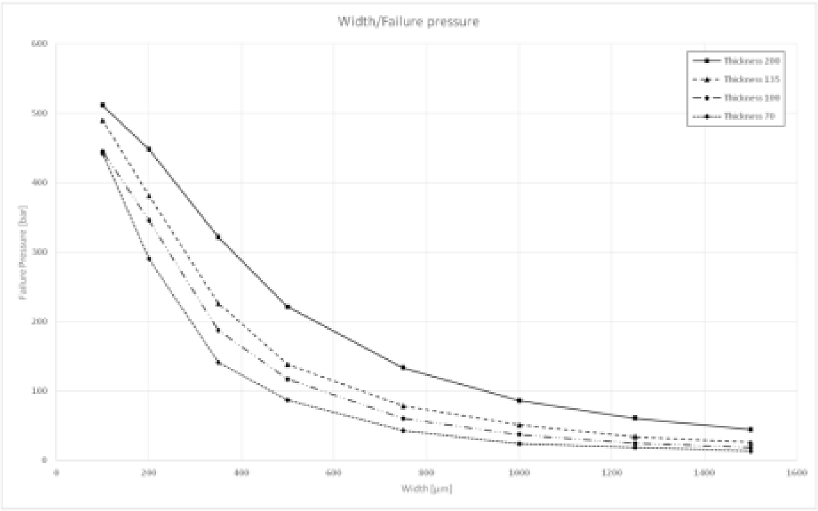


2015-2020: Achievements

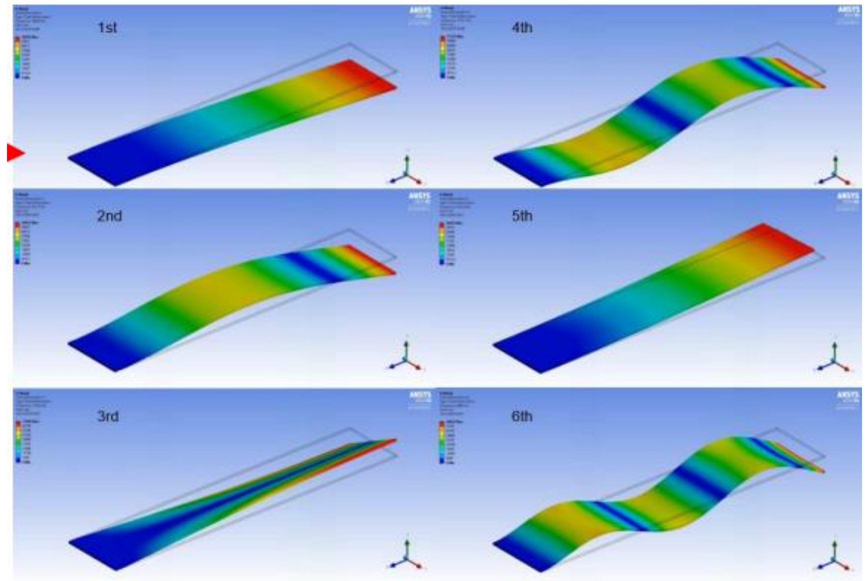
Silicon as a structural material





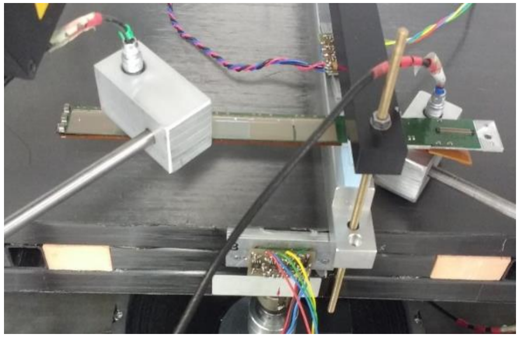


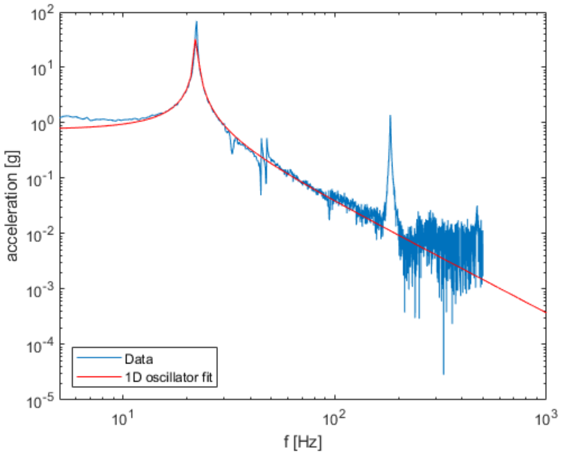
1st to 6th Vibration modes of a Cantilever all Silicon ladder



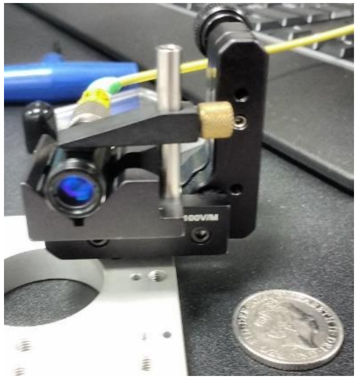
New facilities for vibration analysis and stability measurement

Vibration table

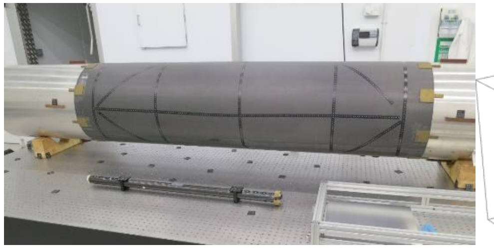


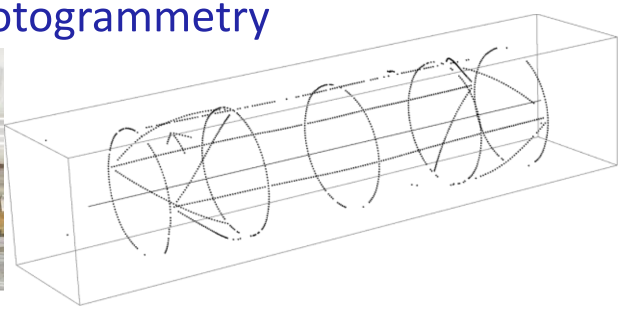


Frequency Scanning Interferometry



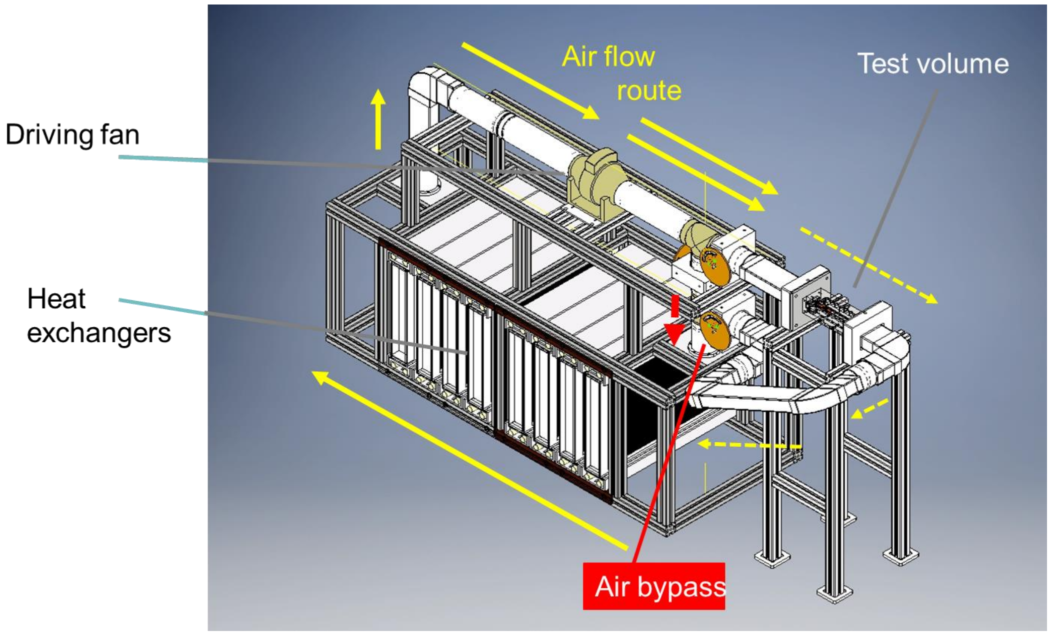
Photogrammetry

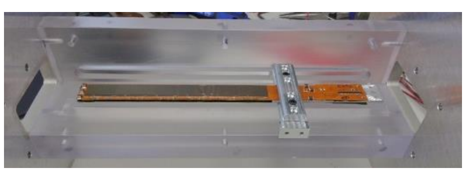


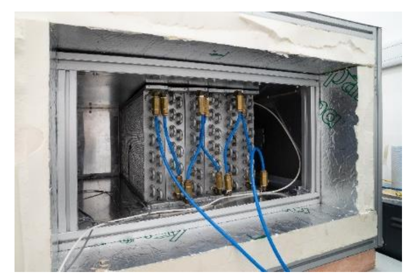


2015-2020: Achievements

New air flow facility







Outreach

We could have made better on this…

15 publications:
- 2 Journal papers
- 1 Conference proceedings
- 9 Conference presentations
- 1 Scientific note
- 2 Posters

At least 3 more Journal papers are under submission

What next?

H2020-INFRAINNOV-2019-2020: Demonstrating the role of Research Infrastructures in the translation of Open Science into Open Innovation
INFRAINNOV-04-2020: Innovation pilots
Type of Action: Research and Innovation action

Title of proposal: **Advancement and Innovation for Detectors at Accelerators**
Short name: **AIDAinnova**

WP10: Advanced Mechanics for Tracking and Vertex detectors

Work Package number	10		**Lead beneficiary**		CERN - CSIC	
Work Package title	**Advanced Mechanics for Tracking and Vertex Detectors**					
Participant number	1	31	36	22	2	15
Short name of participant	CERN	CSIC	CSEM	INFN	LIT	MPG-HLL
Person months per participant:	9.2 (36.8)	11 (24.5)	4 (8.5)	4 (8)	6.7 (6.8)	2.8 (6.2)
Participant number	11	8	26	43	13	
Short name of participant	WORK SHAPE	CNRS	NTNU	UOXF	ETALON	
Person months per participant:	2.5 (2.5)	35 (0)	4.9 (10.1)	9 (23.8)	6.7 (4.3)	
Start month - End month	M1- M48					

Objectives

Task 10.1. Coordination and Communication

See introductory section on page 29.

Task 10.2. Engineering of optimised cooling substrates

- Develop the process of cooling channel integration in CMOS structures into scalable solutions
- Define the optimal geometrical features attainable for 3D printed ultra-thin cold plates in metal alloys and ceramic composites
- Implement the full integration of cooling features into ultra-light carbon composite structures

Task 10.3. Micro-connectivity

- Define advanced engineered solutions for the hydraulic interconnection of multiple micro-structured silicon cold plates

Task 10.4. Supercritical CO2 as refrigerant

- Characterise Supercritical CO2 (sCO2) as a possible ultra-effective single-phase refrigerant for "warm" detector cooling
- Study the design of new supercritical heat exchangers for optimal energy recovery at higher temperatures in transcritical CO2 cycles

Task 10.5. Characterisation of ultra-light structures

- Evaluate the feasibility of a new version of the existing Frequency Scanning Interferometry (FSI) instrumentation suited for use as an accurate survey of ultra-light and small detector structures

- ➢ A small but very motivated network
- ➢ Keeping cohesion beyond the project itself
- ➢ Consistent step forward in AIDAinnova:
  - Alternative production methods
  - Hydraulic interconnections
  - Large leverage on 3D printing
  - New refrigerants
  - Advanced ultra-light structure analysis
  - Full use of the facilities developed
  - Direct involvement of industrial partners

Looking forward for even more achievements!