AHEAD
ADVANCED HEAT EXCHANGE DEVICES

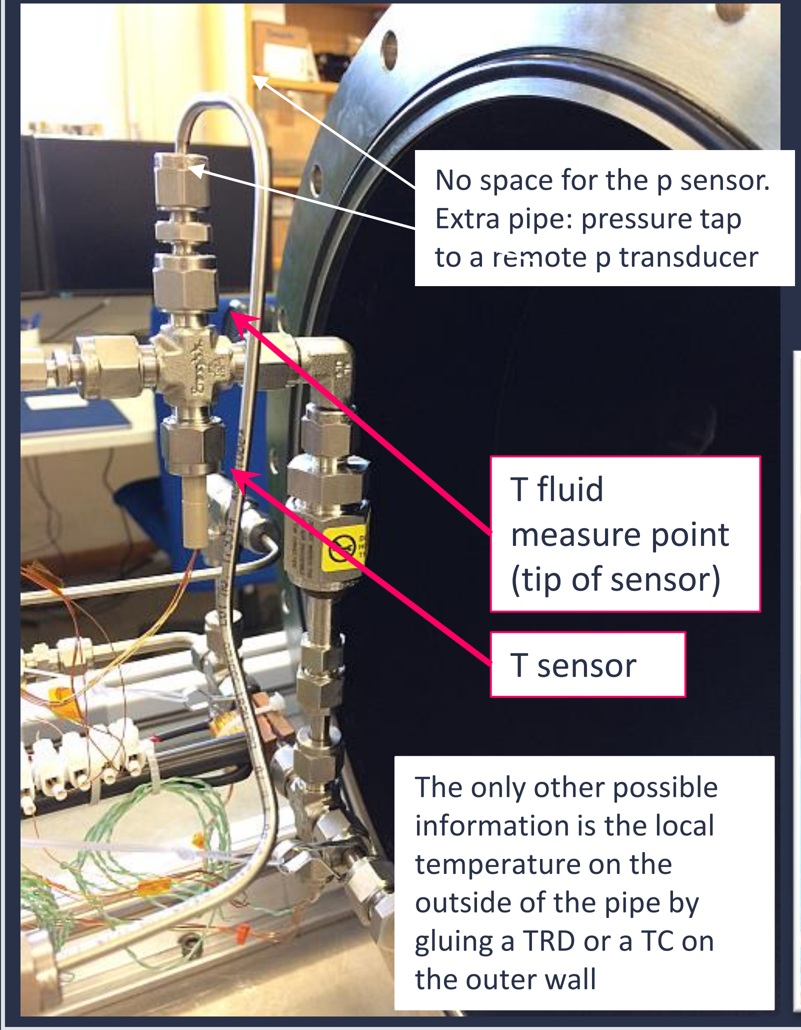
Forum on Tracking Detector Mechanics 2023
31 May 2023 to 2 June 2023
Eberhard Karls Universität Tübingen

“3D printed pipes including sensors and heaters for thermal management systems in space and on earth”

CERN
Chrysoula Manoli

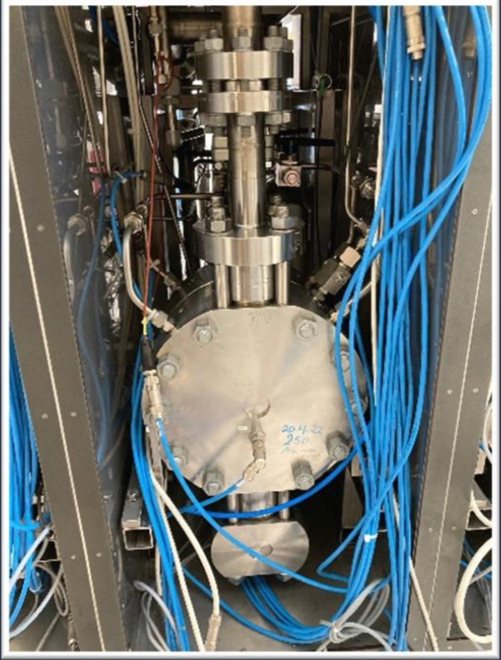
Motivation

Fluid's monitoring → Condition of the fluid locally

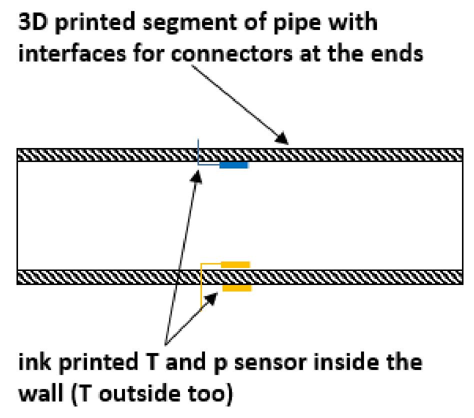


Current limitations

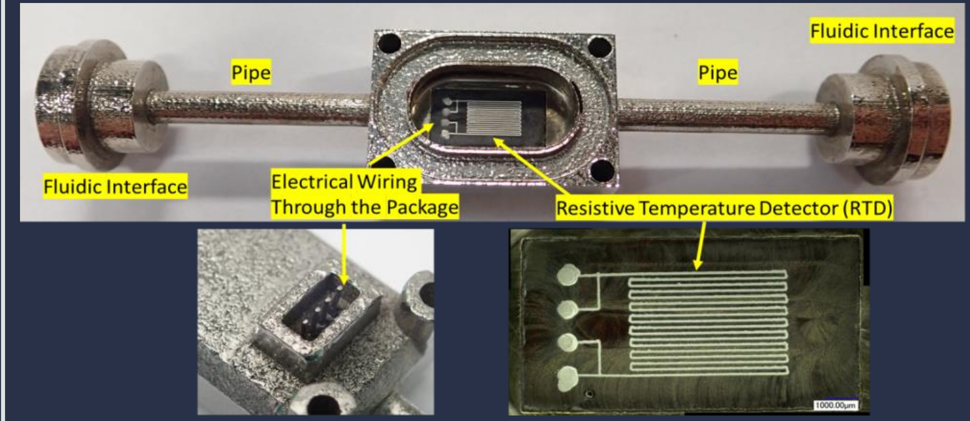
- Lack of space
- Risk of leakages
- Disturbance to the flow
- Plenty of wires



Idea



Prototype

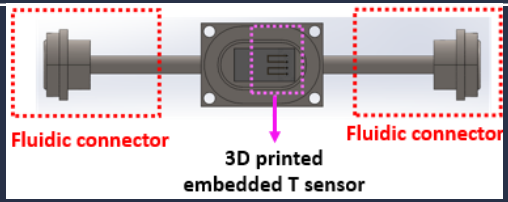


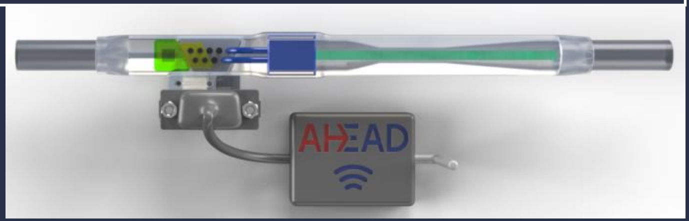
Demonstration of the SWaP prototype, ATTRACT Phase-1

Concept

*ATTRACT: Developing Breakthrough **detection and imaging technologies** for science and society*

	ATTARCT Phase 1 (2019 – 2020)	ATTRACT Phase 2 (2022 – 2024)
Project:	**SWaP** →	**AHEAD**
Partners:	CSEM/ CERN	CSEM/ CERN/ TAS/ LISI/ INANOE/ NTNU
Technology:	Additive Manufacturing • Selective Laser Melting • Aerosol Jet Printing	Additive Manufacturing • Selective Laser Melting (**STOP & RESUME**) • Aerosol Jet Printing
Embedded devices:	• Temperature sensor (AJP)	• Temperature sensor (AJP and **COTS**) • Extension to fluid measurements (pressure, flow rate) • Heater (AJP) • Energy Harvester
Communication:	Wired	Wired & **Wireless**





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AHEAD ADVANCED HEAT EXCHANGE DEVICES
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NTNU Norwegian University of Science and Technology
inanoEnergy Powering industries, startups and cities.

AHEAD ⊢ Electric functions in 3D printed metal parts

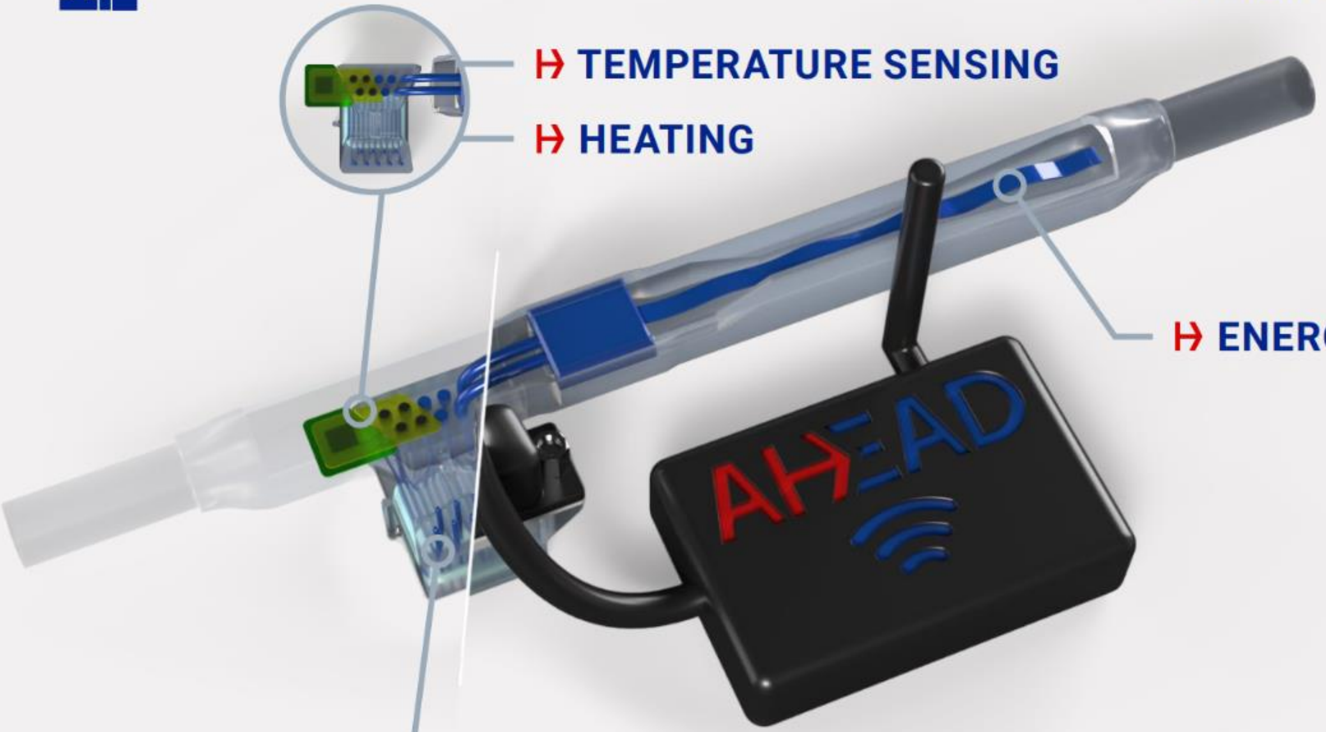
Bring industry 4.0 and IoT into mechanical parts

- IN-SITU MEASUREMENT
- WIRELESS
- ACTIVE ELEMENTS
- MASS REDUCTION
- COMPACTNESS
- NO ASSEMBLY

AHEAD
ADVANCED HEAT EXCHANGE DEVICES

Technology bricks for

- FOOD INDUSTRY
- PHARMACEUTICS
- ENERGY SYSTEMS
- MACHINE TOOL
- AERO SPACE
- MEDTECH
- AUTOMOTIVE
- BUILDINGS THERMAL MANAGEMENT



Project partners

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LEARN MORE

This project has received funding from ATTRACT, a European Union's Horizon 2020 research and innovation project under grant agreement No 101004462

Key Enabling Technology Bricks

☆ 1. Pipe segment incl. interfaces

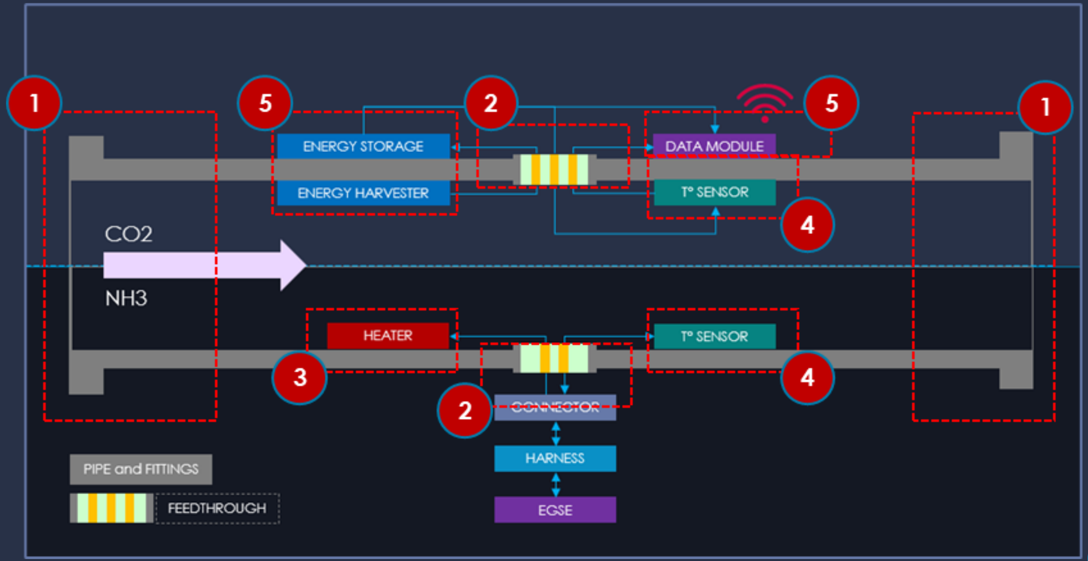
☆ 2. Electrical feedthrough and connector interface

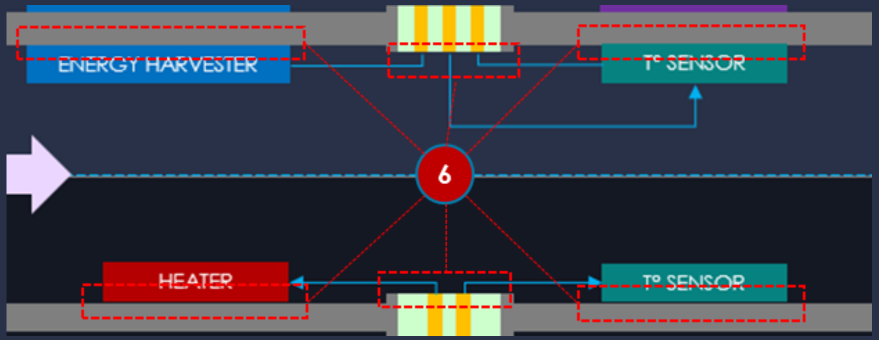
3. Aerosol Jet Printed heating elements

☆ 4. Aerosol Jet Printed Resistance Temperature Detector (RTD)

5. Energy Harvester (EH) from fluid circulation

6. Integration of COTS elements
→ Heater (3) RTD (4), and EH (5)





☆ PART OF SWAP USE-CASE ARCHITECTURE (ATTRACT PHASE 1)

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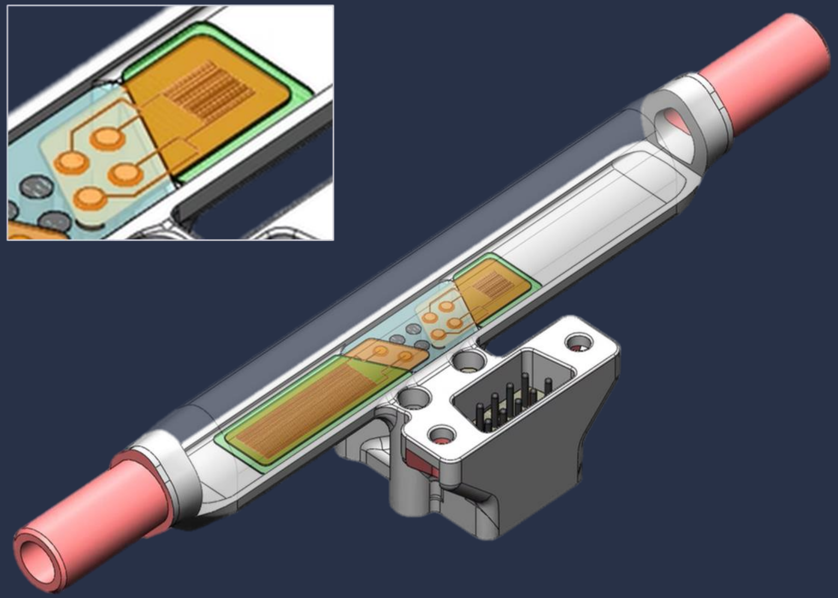
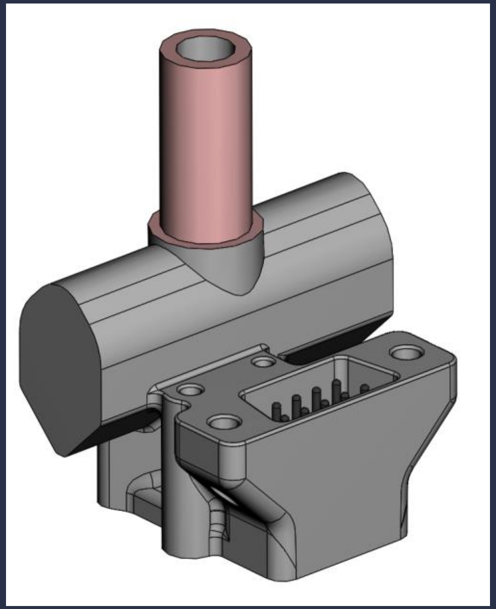
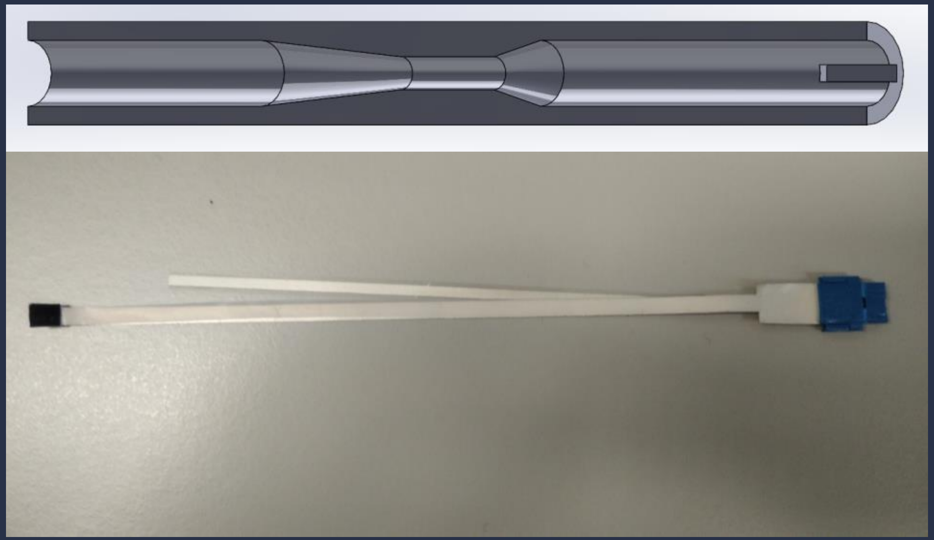
Technical Challenges

- Stop & resume 3D printing
- Insulation material/ Feedthrough casting
- Energy Harvester membranes





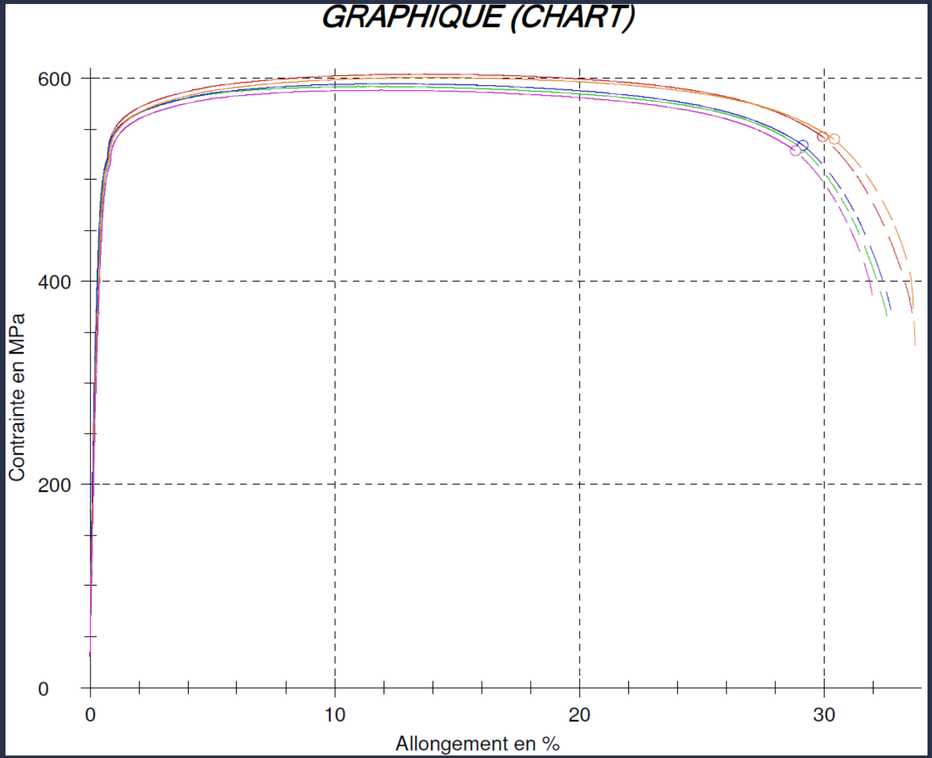


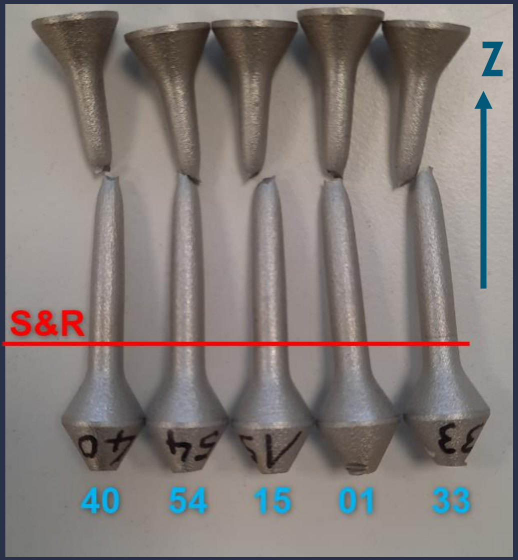
Stop & resume 3D printing

LISI RESULTS

Material characterization and qualification → Mechanical

- No rupture in stop and resume line
- Rp0.2 and Rm slightly below mapping results – 0,8%





(SERIES STATISTICS)

Mapping N° 6214 – NO S&R

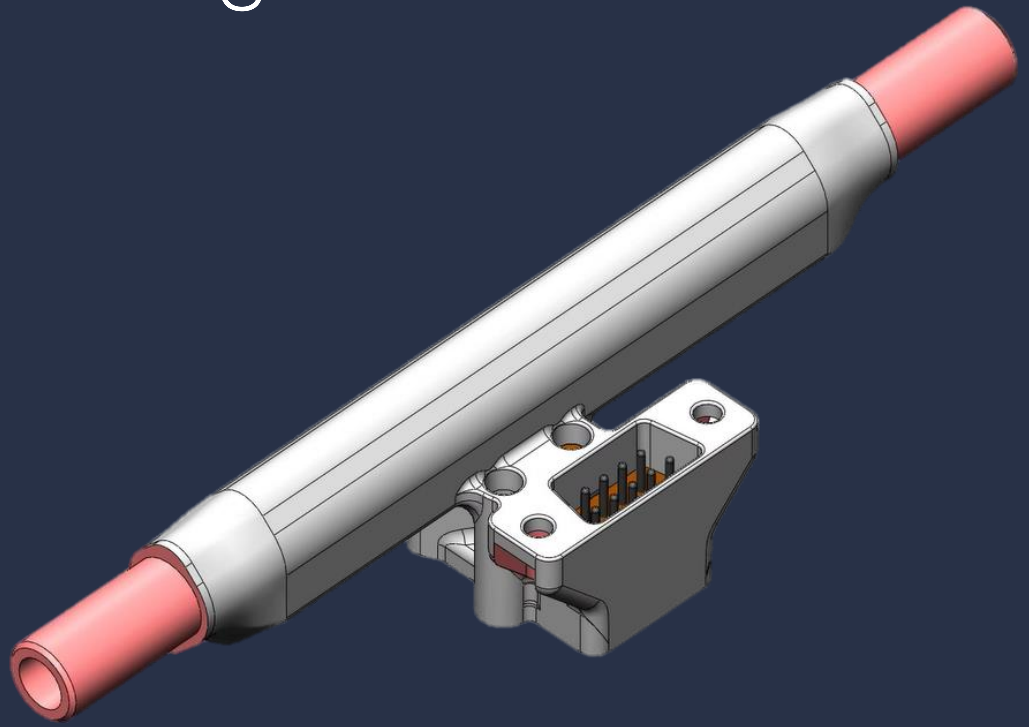
6214 n = 77	E GPa	$R_{p0.2}$ MPa	R_m MPa	A_t %	S_0 mm²
max	156	504	608	39,3	28,65
min	99,9	480	595	37,2	28,21
$\bar{x}$	140	493	601	38,1	28,41

(SERIES STATISTICS)

JOB N°6397-6402 – WITH S&R

6402 n = 5	E GPa	$R_{p0.2}$ MPa	R_m MPa	A_t %	S_0 mm²
max	159	494	604	33,7	28,46
min	114	487	588	32,0	28,27
$\bar{x}$	140	489	596	32,9	28,36

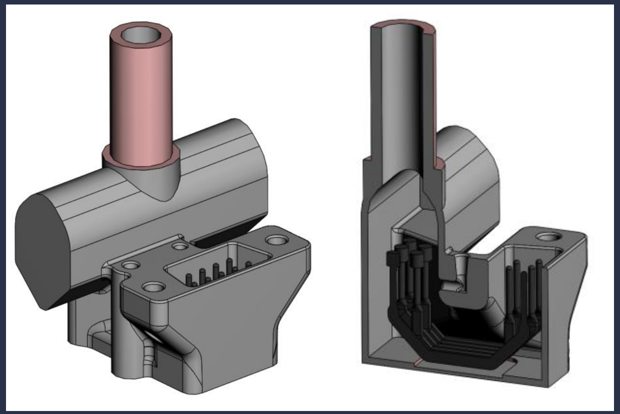
Insulation material/ Feedthrough casting



Technical Specifications

- Low viscosity for casting
- Low shrinkage effect

Testing at CERN



- Chemical compatibility with the fluid (CO_2/ NH_3 for TAS)
- Feedthrough tightness & pressure

Insulation material/ Feedthrough casting

Chemical compatibility with CO_2

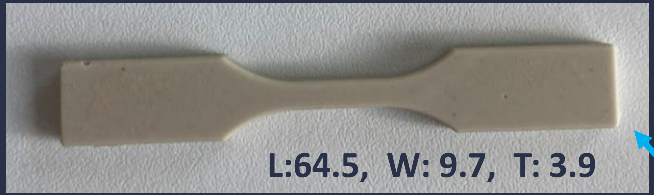
Araldite after CO_2:

- 0.04gr higher mass
- lower deformation

Matrimid after CO_2:

- 0.08gr higher mass
- higher deformation

Araldite



Matrimid

Samples	m (gr)	σ (Mpa)		ε (%)		E (Mpa)	
		mean	stdv	mean	stdv	mean	stdv
As built	3.09	61.4	2.7	3.7	1.2	1792.9	521.2
CO2	3.13	51.7	5.3	2.6	0.5	2021.3	324.2
As built	2.25	58.8	12.0	6.2	1.8	1003. 1	358.6
CO2	2.33	65.8	17.1	8.5	1.3	765.4	109.7

Insulation material/ Feedthrough casting

- Both resins selected show cracking and/or delamination when casted and cured in the electrical feedthrough
- Pressure tests performed with Araldite samples reveal leakage issue

Feedthrough samples with Araldite

Results

- Pre-test by CSEM
  - Cracks and delamination signs observed
- He and CO_2 leak test (CERN)
  - Not leak tight
  - Leakage located at the interface between resin and metal
- Pressure test with DiWater (CERN)
  - Up to 43 bar could be achieved

Insulation material/ Feedthrough casting

Cracking/ delamination/ bubbles:

- Resin shrinkage during curing
- CTE mismatch between resin and metal
- Surface topology (e.g too smooth) and or shapes (e.g. edges corners)
- Too large voids to be filled with resin
- Lack of adhesion between resin and metal

Corrective actions:

- Cast with part at higher temperature (limit bubbles)
- Perform outgassing layer by layer (remove bubbles),
- Curing over a longer time period and at lower temperature (limit shrinkage & CTE issues)

Results:

- cracks in some cavities
- poor adhesion to the metal on the edges of the cavities
- spacing and shrinkage for all considered sizes

DISCARDED

ARALDITE: not good results

MATRIMID: hard to process/ very brittle/ Unsuited for TAS

EPOXY by Masterbond **(TO BE TESTED)**:

low shrinkage/ CTE close to 316L/ easy to process/ Meets NASA low outgassing specification

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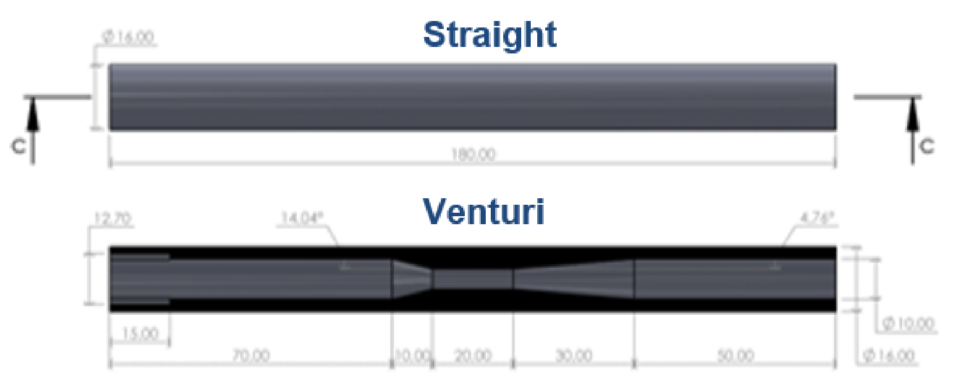
Energy Harvester Membranes

1: piezo, **2**: tribo, **3**: hybrid

S: straight tube, **V**: venturi tube



Energy Harvester membranes
- Piezoelectric
- Triboelectric
- Hybrid (piezo + tribo)

A/C voltage

Rectifier bridge
- Commercial component
- Built-in diodes

D/C voltage

Capacitor
- 1 μF
- 10 μF
- 100 μF
- 450 μF

Requires 5V

Input → Power → Voltage Monitor / **5V** Capacitor (500 uF)

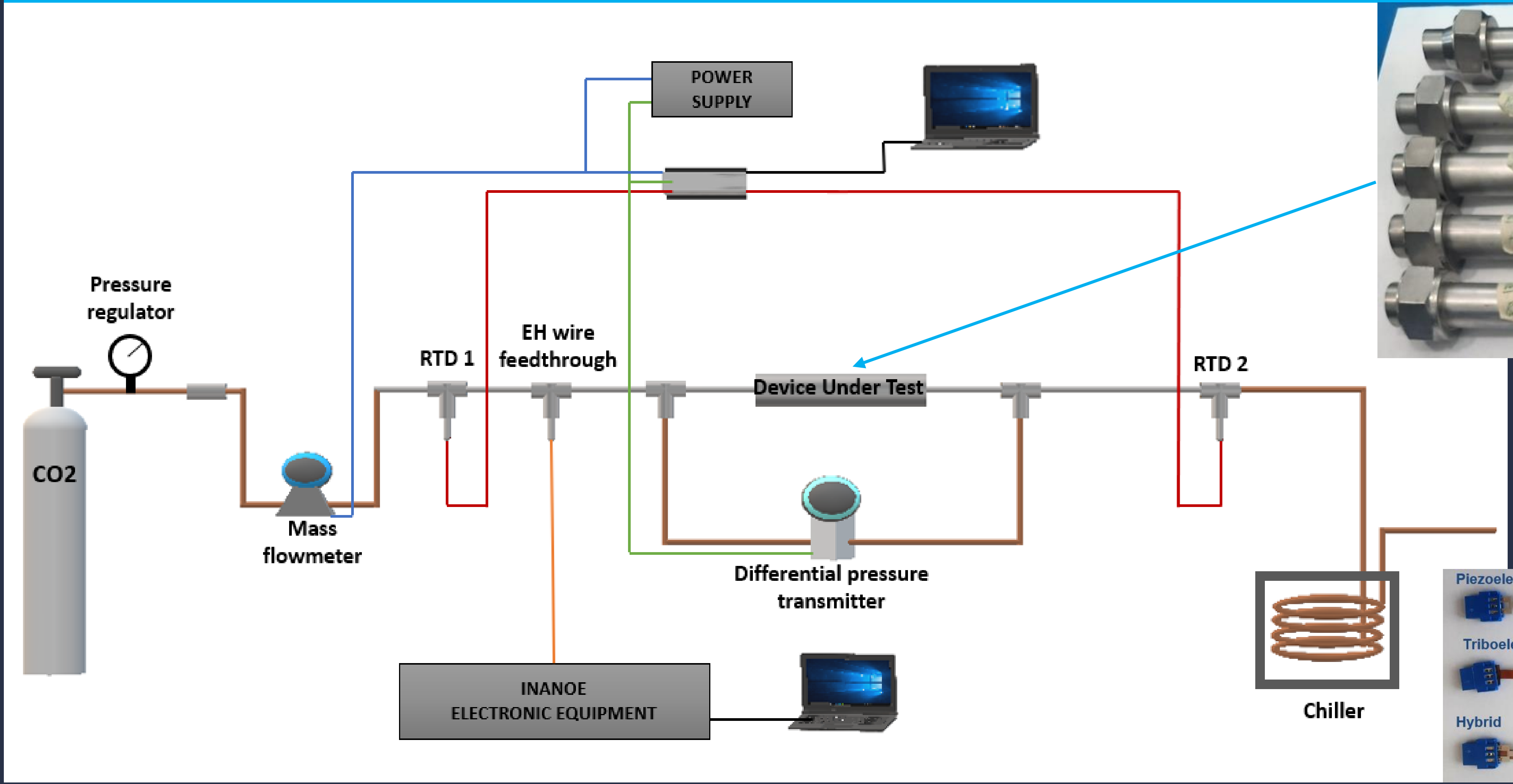
Voltage Monitor — Monitoring — **5V** Capacitor (500 uF)

INANOE TESTS:

Hybrid inside **venturi** presents the most promising results

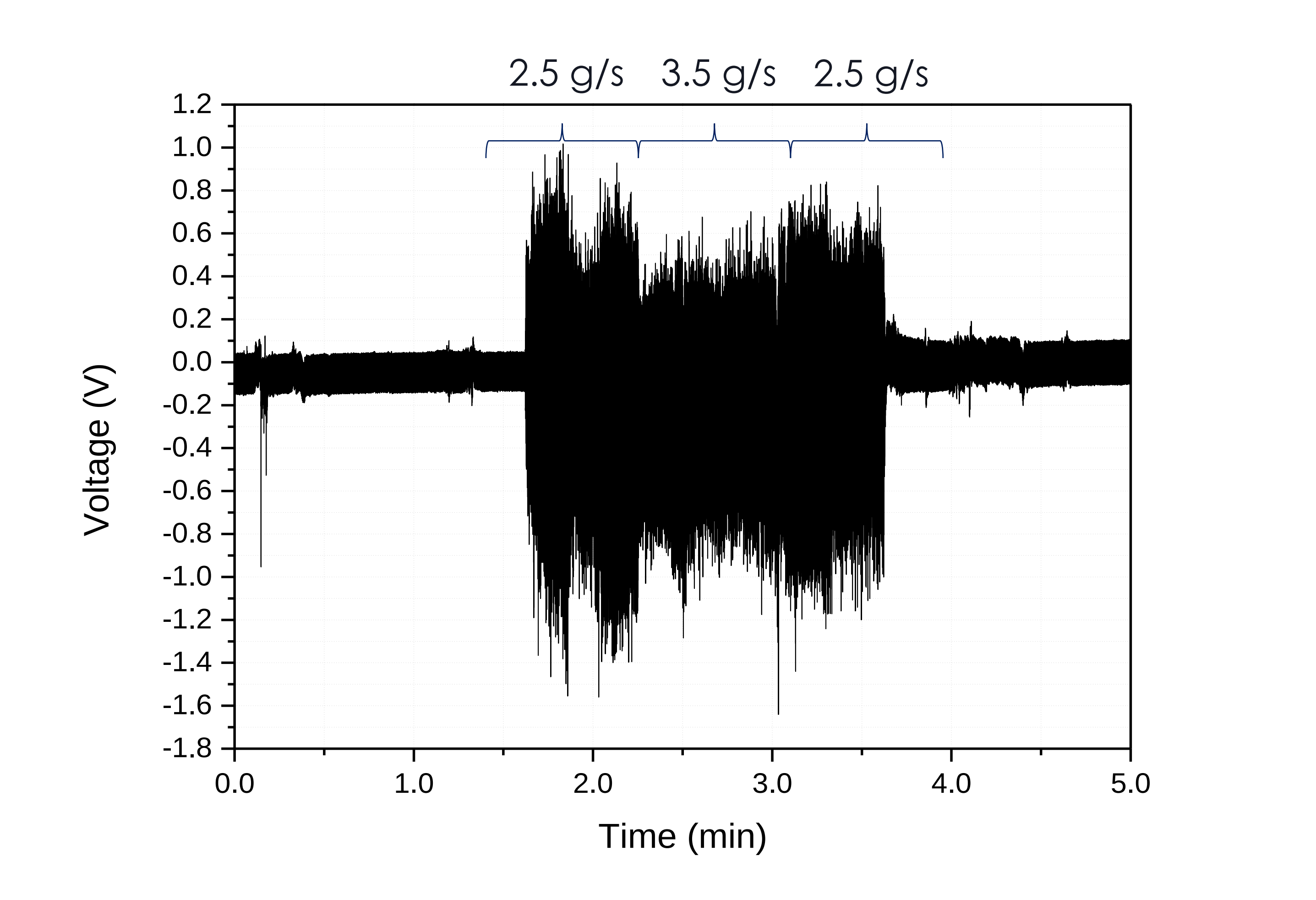
Energy Harvester Membranes

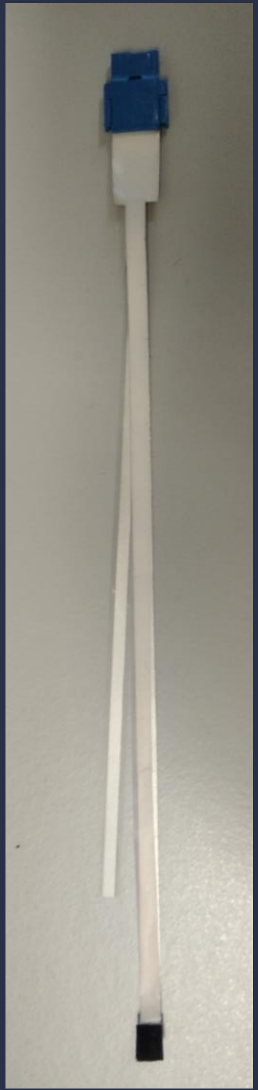
CERN TEST SETUP



Energy Harvester Membranes

Hybrid Generator inside Venturi – CO_2 Gas Flow



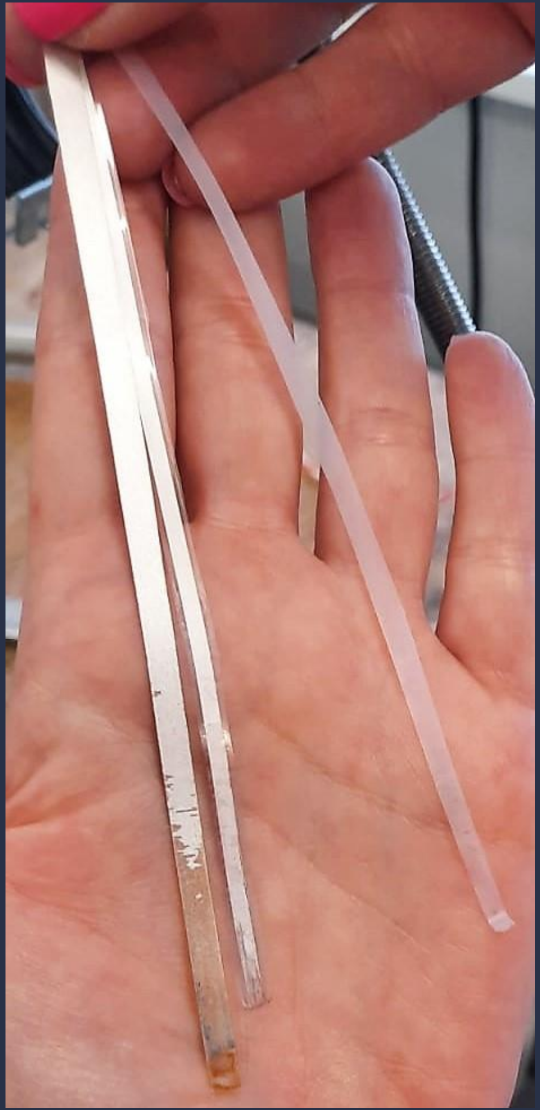


Energy Harvester Membranes

FIRST RESULTS

- Higher flow rates → lower voltage
- Membranes failure in one end → CO_2? low temperature? movement?
- Tribo may affect the instrument
- Results are not repeatable (not reliable)

- **Tests with compressed air (before CO_2):**
  - Find out which flow rate generates more voltage
  - Perform tests under same conditions → verify repeatability & reliability
- **Test different membranes** (carbon based)
  - Durability enhancement



Conclusions & Future work

1st year of the project progress:

- **KET bricks are tested individually to:**
  - Identify the problems of each process
  - Targeted corrective actions
  - Verify repeatability and reliability at prototype level
  - Ensure the best performance of the final device

2nd year of the project plan:

- **Corrective actions, redesign, retesting to:**
  - Electrical feedthrough → tightness
  - Energy Harvester membranes → functionality
  - Other bricks

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END OF PRESENTATION

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