



Forum on Tracking Detector Mechanics 2023

31 May 2023 to 2 June 2023

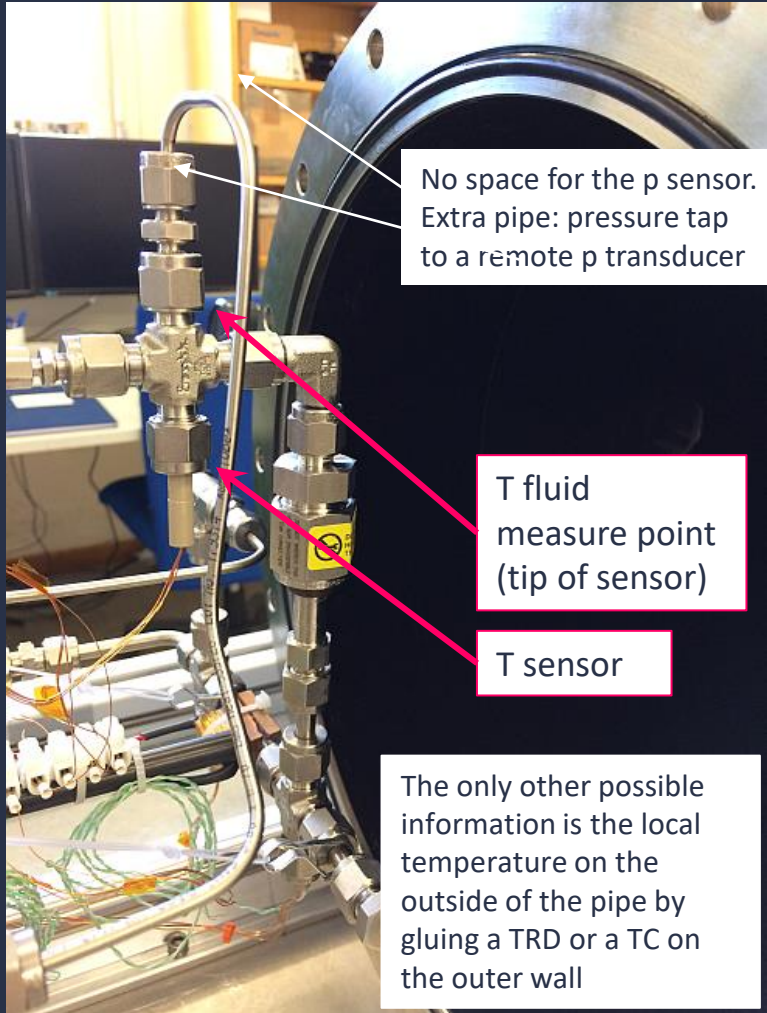
Eberhard Karls Universität Tübingen

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

CERN
Chrysoula Manoli

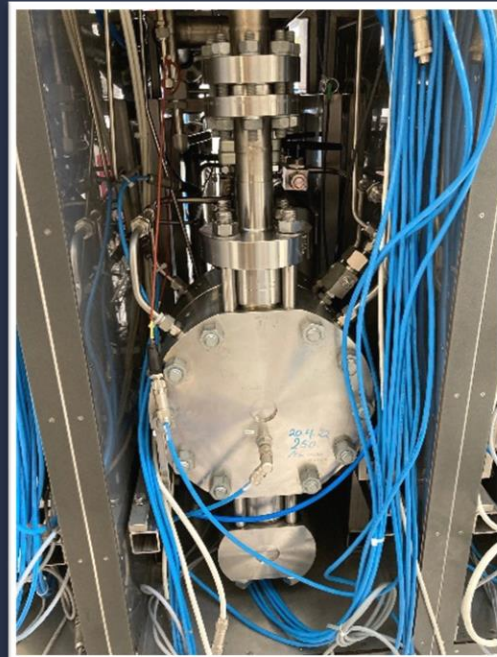
Motivation

Fluid's monitoring → Condition of the fluid locally



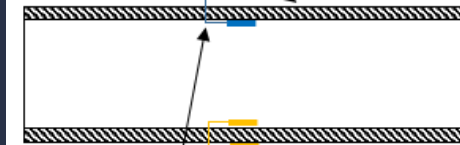
Current limitations

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



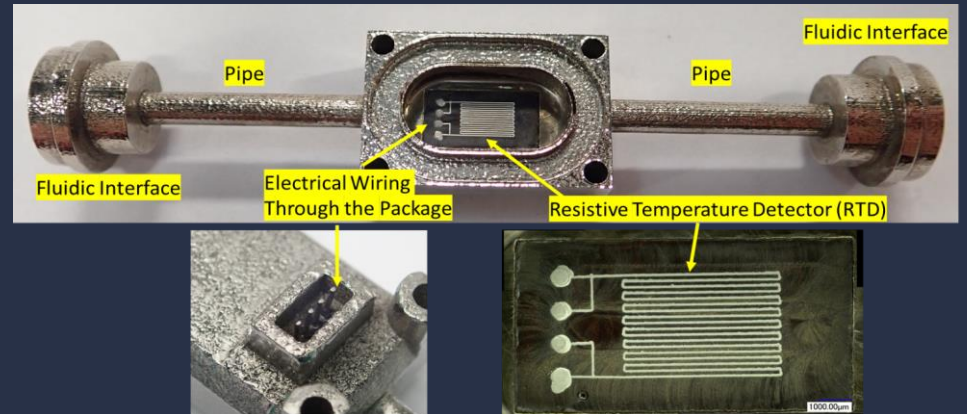
Idea

3D printed segment of pipe with interfaces for connectors at the ends



ink printed T and p sensor inside the wall (T outside too)


Prototype



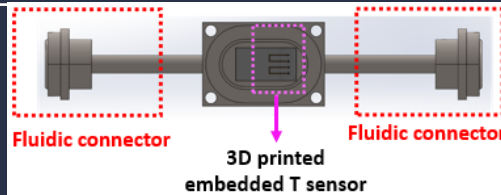
Demonstration of the SWaP prototype, ATTRACT Phase-1

Concept

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

	ATTRACT Phase 1 (2019 – 2020)	ATTRACT Phase 2 (2022 – 2024)
Project:	SWaP 	AHEAD
Partners:	CSEM/ CERN	CSEM/ CERN/ TAS/ LISI/ INANOE/ NTNU
Technology:	Additive Manufacturing <ul style="list-style-type: none"> • Selective Laser Melting • Aerosol Jet Printing 	Additive Manufacturing <ul style="list-style-type: none"> • Selective Laser Melting (STOP & RESUME) • Aerosol Jet Printing
Embedded devices:	<ul style="list-style-type: none"> • Temperature sensor (AJP) 	<ul style="list-style-type: none"> • Temperature sensor (AJP and COTS) • Extension to fluid measurements (pressure, flow rate) • Heater (AJP) • Energy Harvester
Communication:	Wired	Wired & Wireless

3



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

Technology bricks for



FOOD INDUSTRY



PHARMACEUTICS



ENERGY SYSTEMS



MACHINE TOOL



AERO SPACE



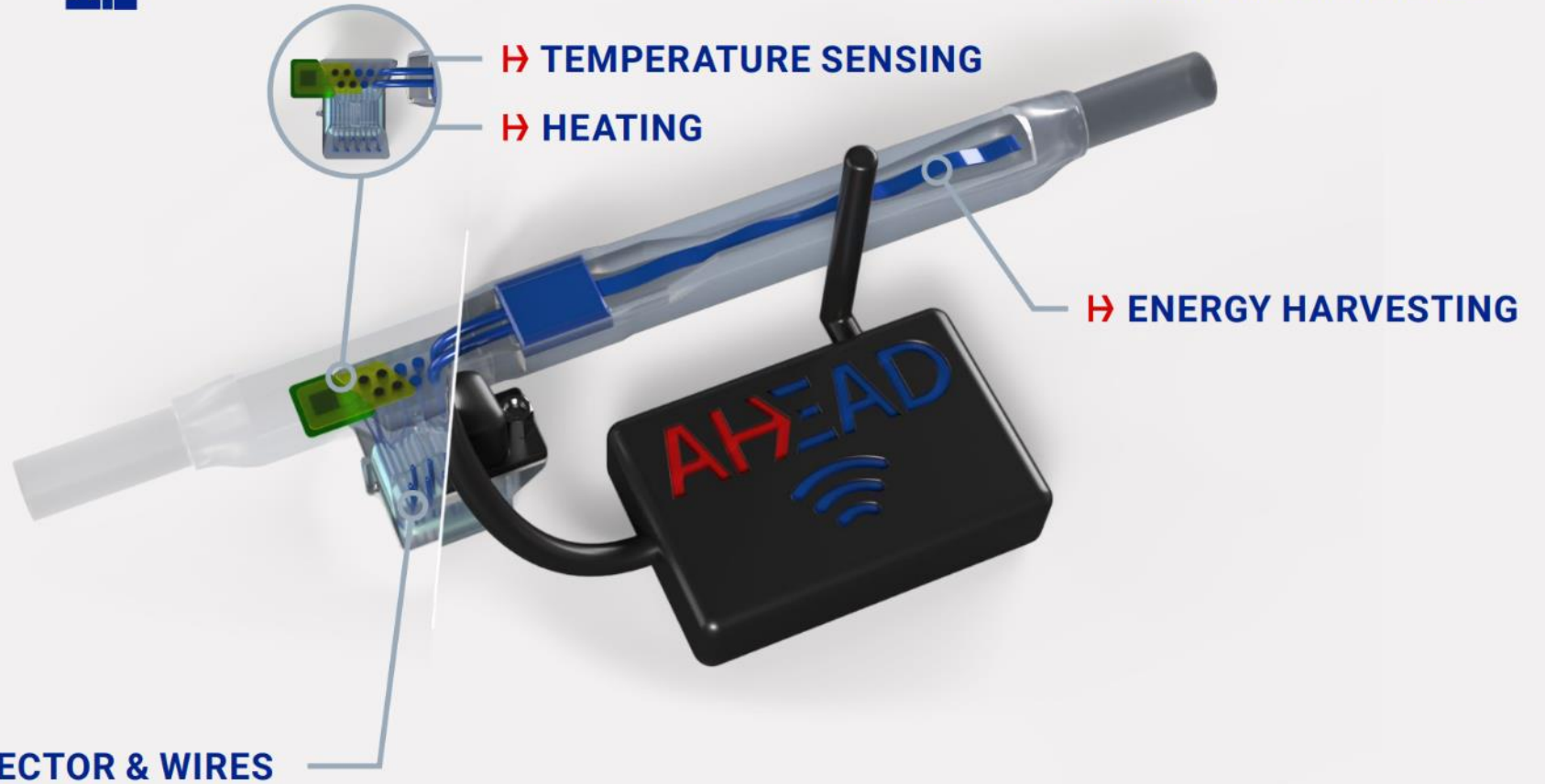
MEDTECH



AUTOMOTIVE



BUILDINGS THERMAL MANAGEMENT



Project partners



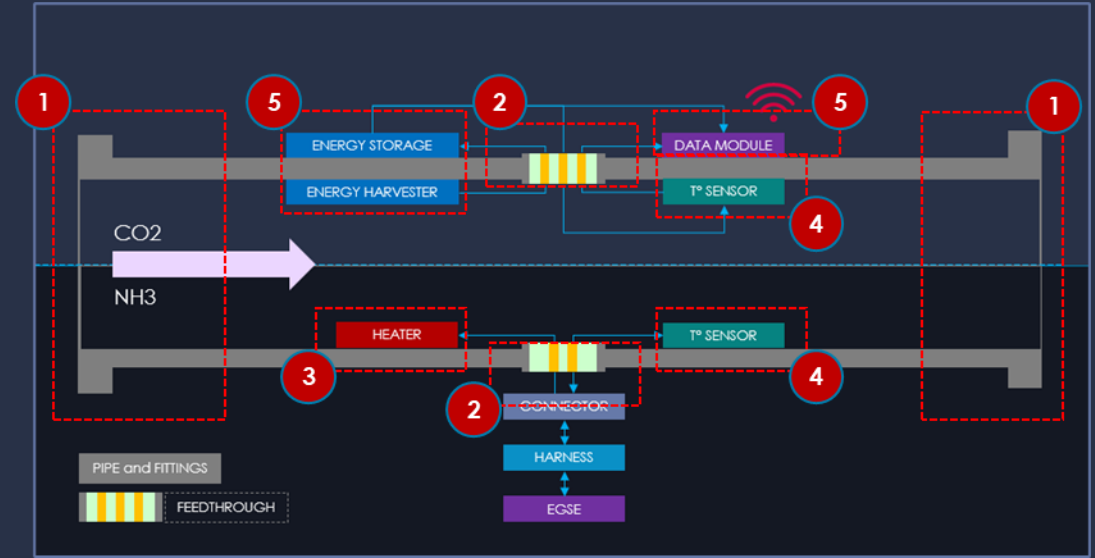
LEARN MORE

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

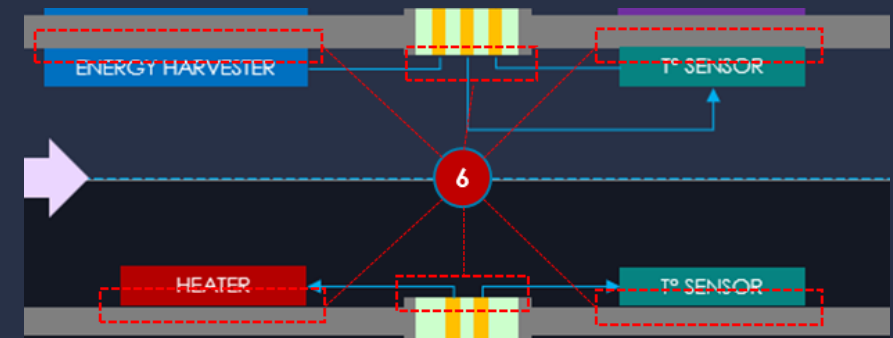


Key Enabling Technology Bricks

- ★ 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)



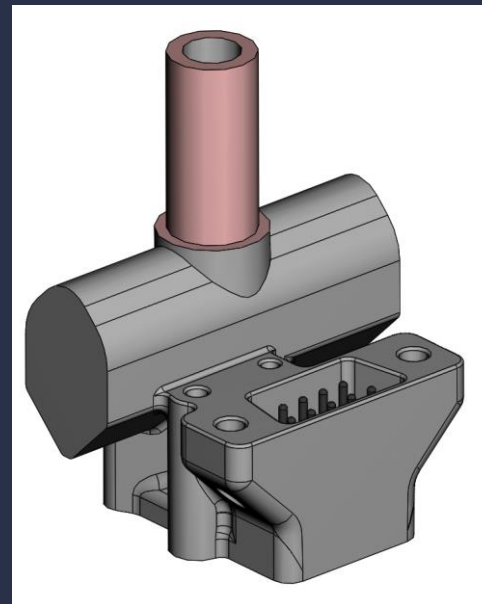
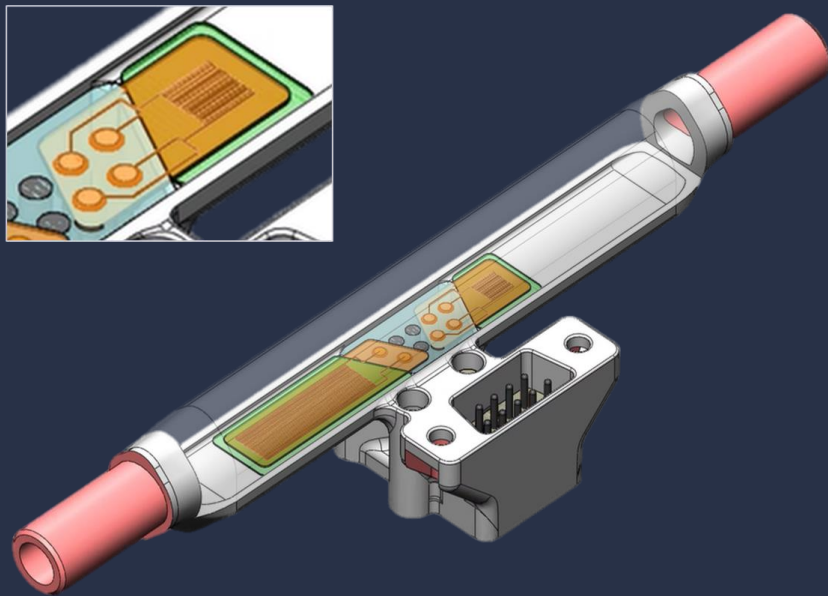
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★ PART OF SWAP USE-CASE ARCHITECTURE (ATTRACT PHASE 1)

Technical Challenges

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

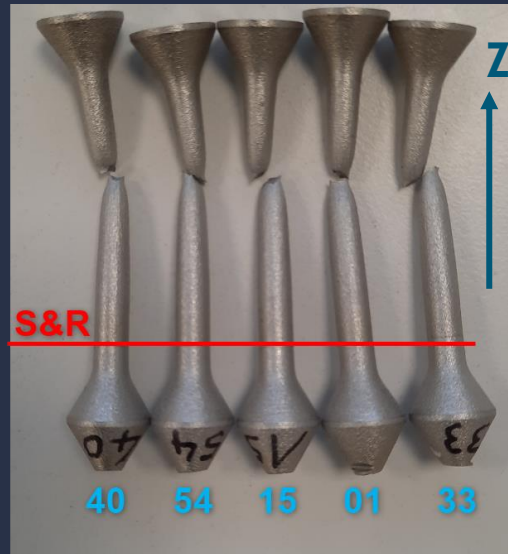
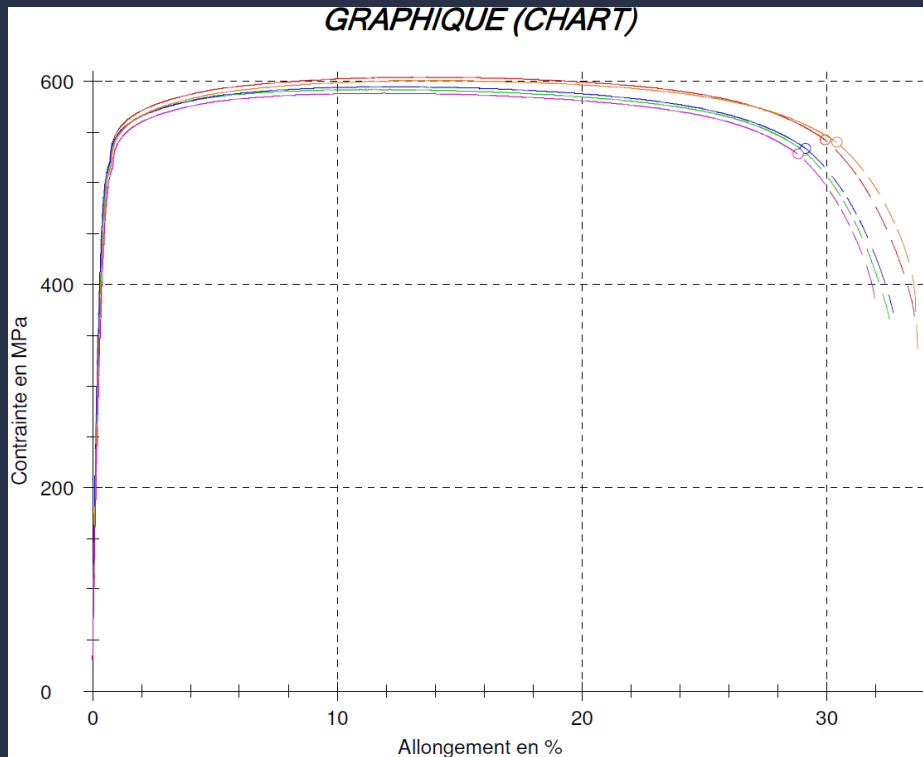


Stop & resume 3D printing



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	Rp0.2 MPa	Rm MPa	At %	S0 mm ²
max	156	504	608	39,3	28,65
min	99,9	480	595	37,2	28,21
x	140	493	601	38,1	28,41

(SERIES STATISTICS)

JOB N° 6397-6402 – WITH S&R

6402 n = 5	E GPa	Rp0.2 MPa	Rm MPa	At %	S0 mm ²
max	159	494	604	33,7	28,46
min	114	487	588	32,0	28,27
x	140	489	596	32,9	28,36

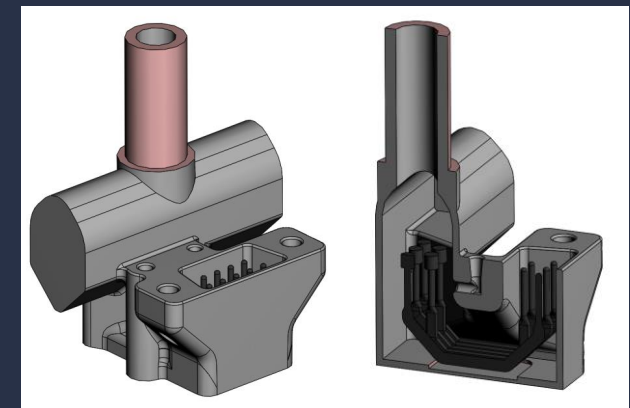
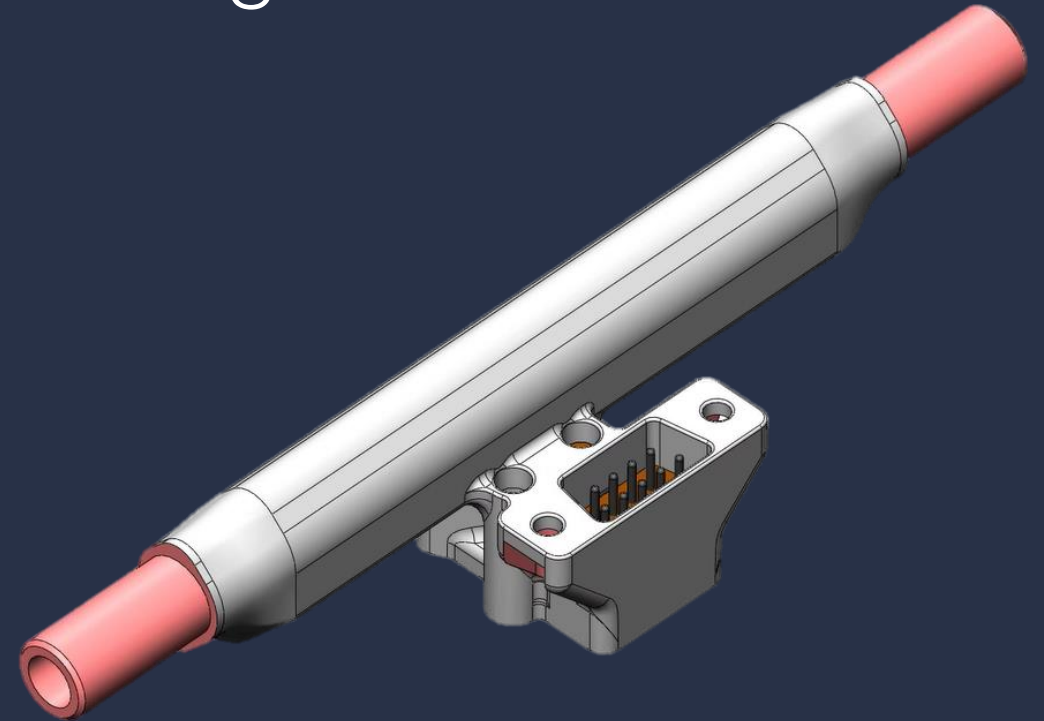
Insulation material/ Feedthrough casting

Technical Specifications

- Low viscosity for casting
- Low shrinkage effect

Testing at CERN

- Chemical compatibility with the fluid (CO₂/ NH₃ for TAS)
- Feedthrough tightness & pressure



Insulation material/ Feedthrough casting

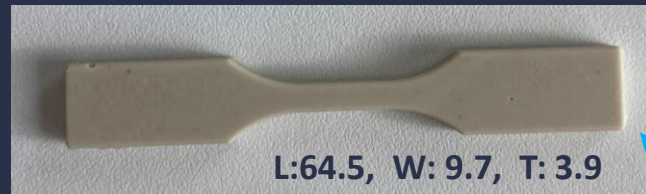
Chemical compatibility with CO2



- Araldite** after CO2:
- 0.04gr higher mass
 - lower deformation
- Matrimid** after CO2:
- 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



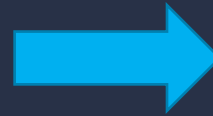
Results

- Pre-test by CSEM
- Cracks and delamination signs observed
- He and CO2 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)

11



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/ Unsuitable for TAS

EPOXY by Masterbond (TO BE TESTED):

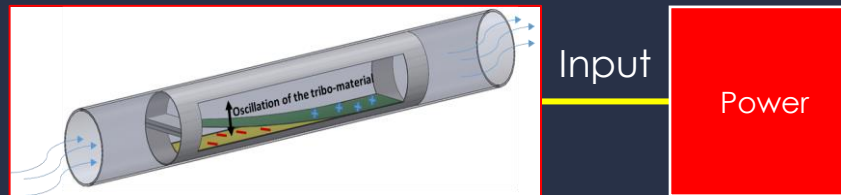
low shrinkage/ CTE close to 316L/ easy to process/ Meets NASA low outgassing specification

Energy Harvester Membranes

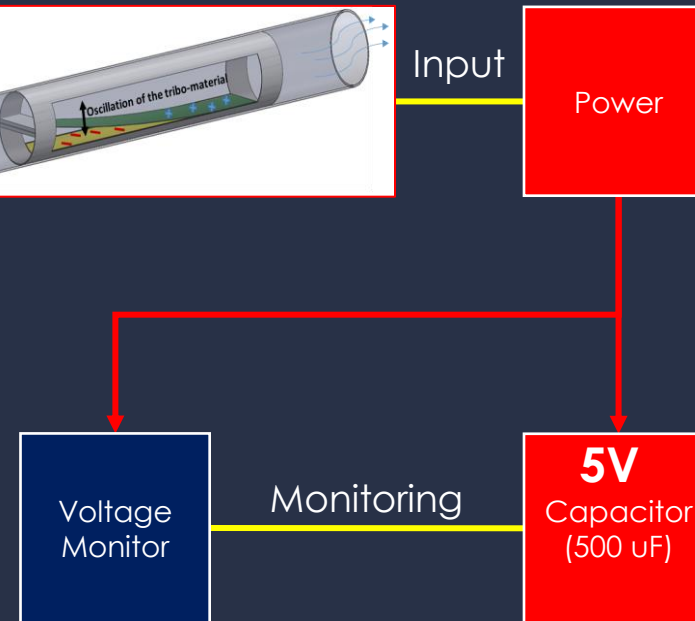
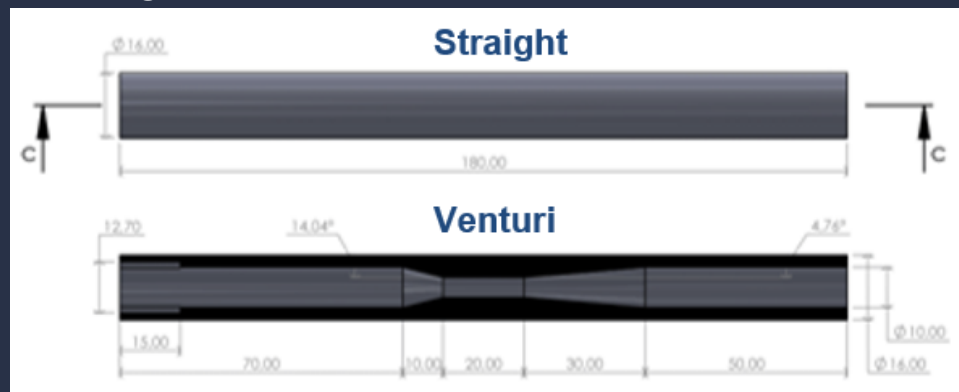
1: piezo, 2: tribo, 3: hybrid



Energy Harvester membranes <ul style="list-style-type: none"> • Piezoelectric • Triboelectric • Hybrid (piezo + tribo) <p>A/C voltage</p>	Rectifier bridge <ul style="list-style-type: none"> • Commercial component • Built-in diodes <p>D/C voltage</p>	Capacitor <ul style="list-style-type: none"> • 1 μF • 10 μF • 100 μF • 450 μF <p>Requires 5V</p>
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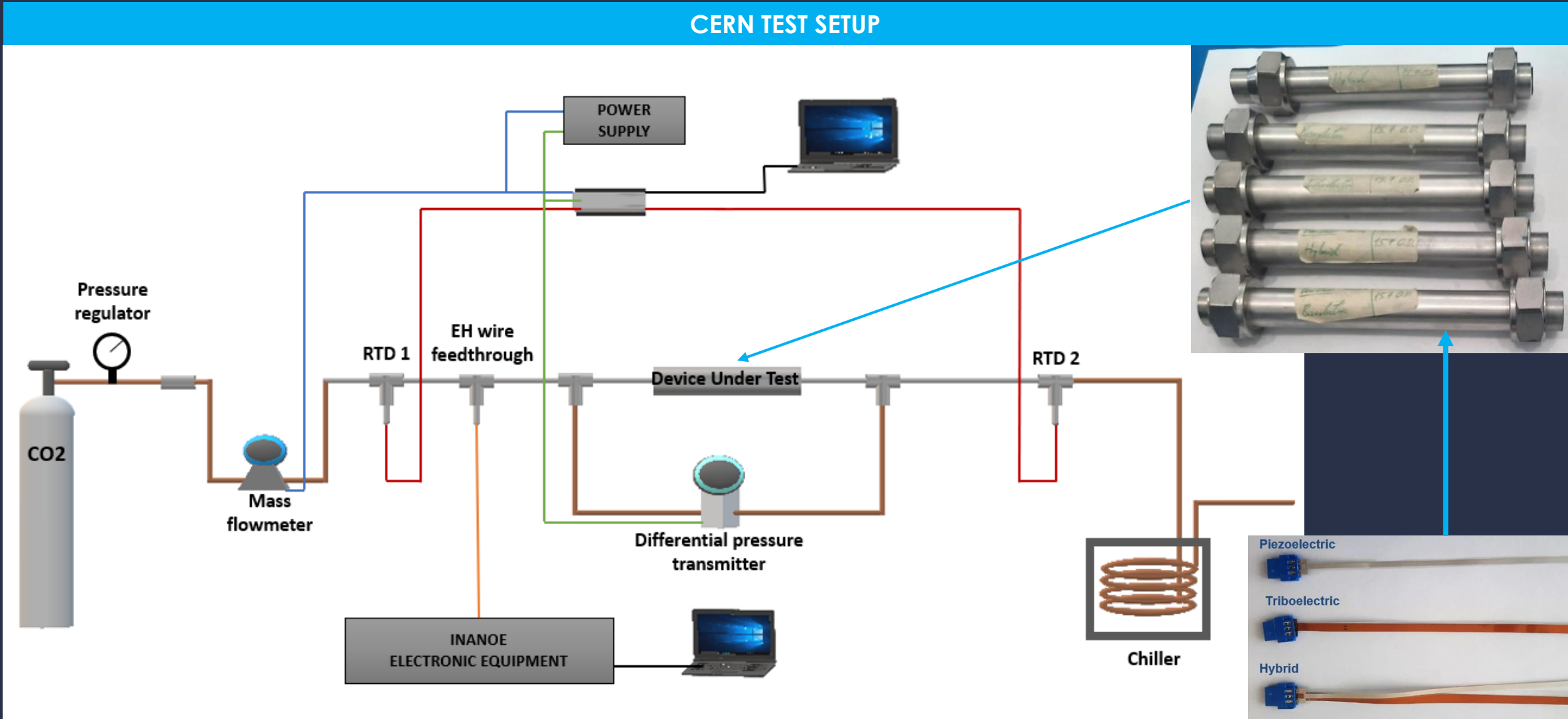
S: straight tube, V: venturi tube



INANOE TESTS:
Hybrid inside **venturi** presents the most promising results

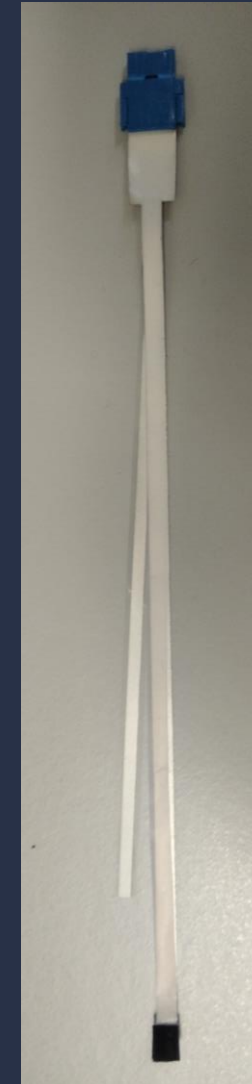
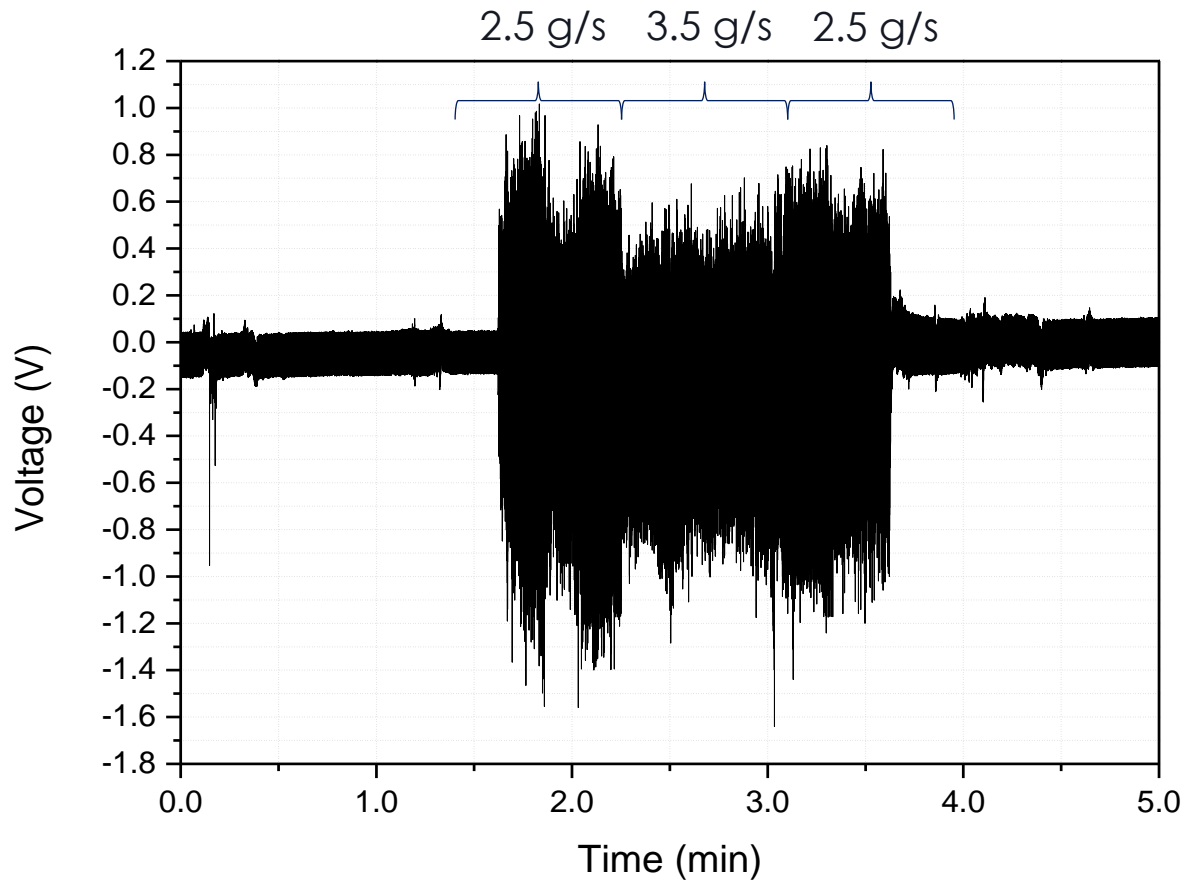
Energy Harvester Membranes

CERN TEST SETUP




Energy Harvester Membranes

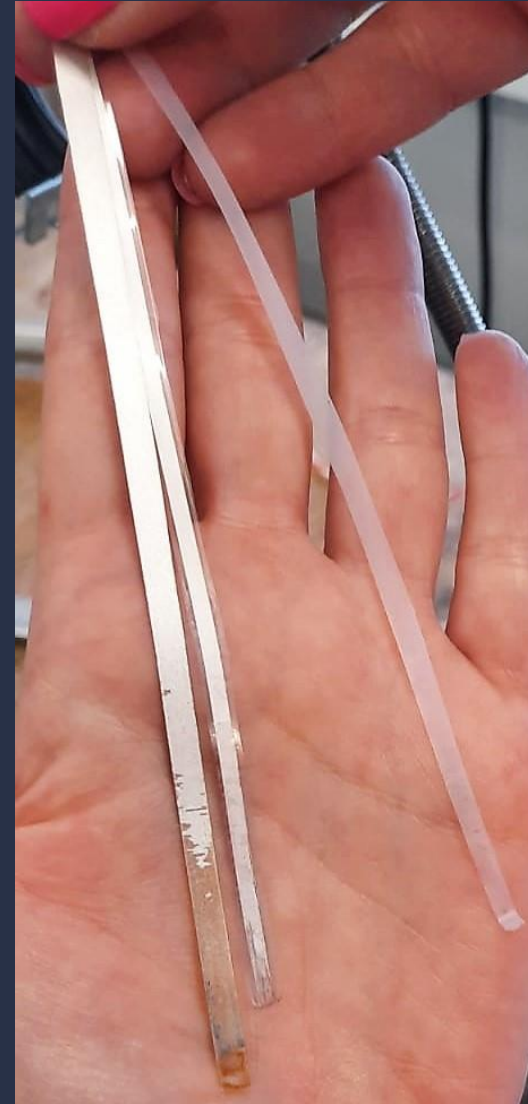
Hybrid Generator inside Venturi – CO₂ Gas Flow



Energy Harvester Membranes

FIRST RESULTS

- Higher flow rates → lower voltage
 - Membranes failure in one end → CO2? low temperature? movement?
 - Tribo may affect the instrument
 - Results are not repeatable (not reliable)
- 
- **Tests with compressed air (before CO2):**
 - 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



AHEAD

ADVANCED HEAT EXCHANGE DEVICES

END OF PRESENTATION