DEMACO

CHMT 2019 – Enschede

Rotor Cooling Concept for the ASuMED Superconductive Motor

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CHMT 2019 – Cryogenic Heat and Mass Transfer, Enschede

Demaco, It’s all about Cryogenius!

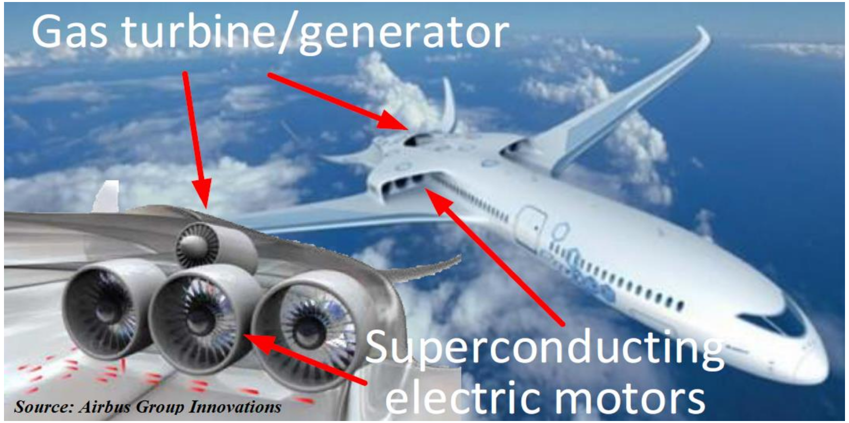
Outline

- Introduction
- Motor Cryostat Concept
- Rotor Cooling System
- Heat transfer & flow analysis
- Status and outlook

Introduction

ASuMED: Advanced Superconducting Motor Experimental Demonstrator

- Air traffic grows 5% each year
- Flightpath 2050 fuel burn and emissions reduction (compared to 2000):
  - 75% CO_2 reduction
  - 90% NO_x and PM reduction
  - 65% noise reduction



Funded by Horizon 2020 programme:

Funded by the European Commission Grant No 723119

"ASuMED has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723119"
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Introduction

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ASuMED: Advanced Superconducting Motor Experimental Demonstrator

- **First fully superconductive motor** prototype for aerospace applications
- **1 MW** power at 6000 rpm
- Overall **efficiency** higher than **99%**

- **Rotor cooling system: design, building, testing**
- **Cryogenic advice**
- **Conditioning equipment for test: design, building, testing**

Motor Cryostat Concept

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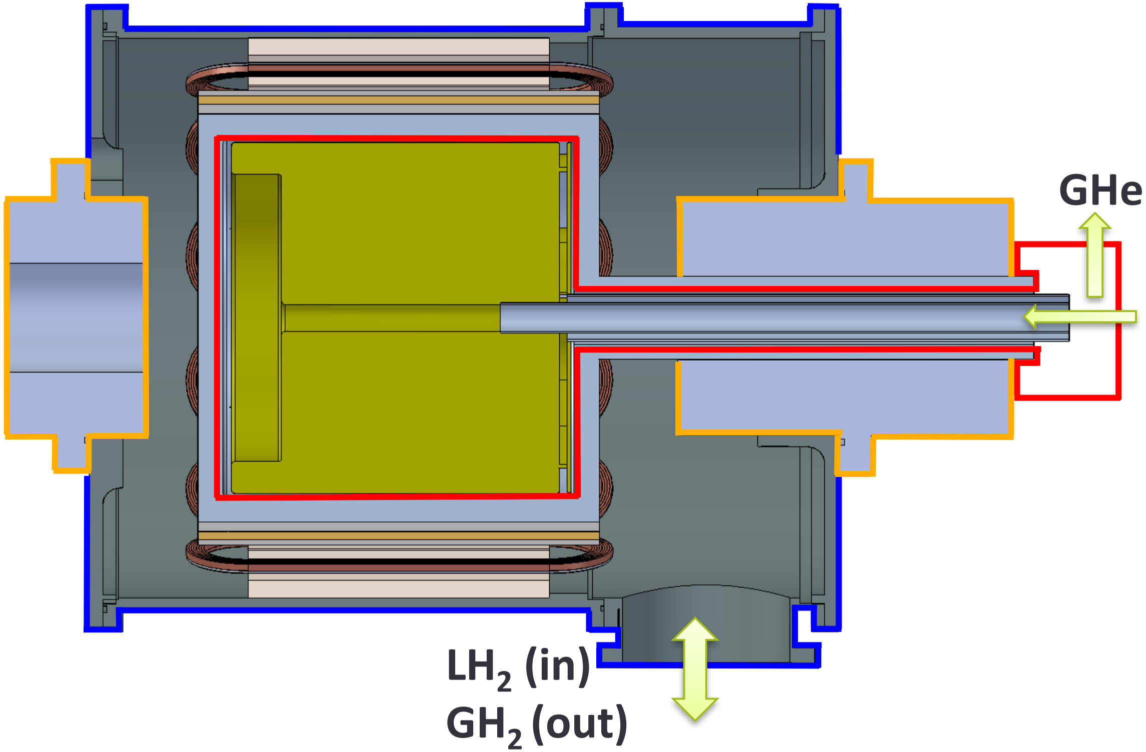
Dual-Cryostat Concept: two separated cryostats for rotor and stator



Stator

- Cryogen: Liquid Hydrogen
- Designed by Oswald

Rotor

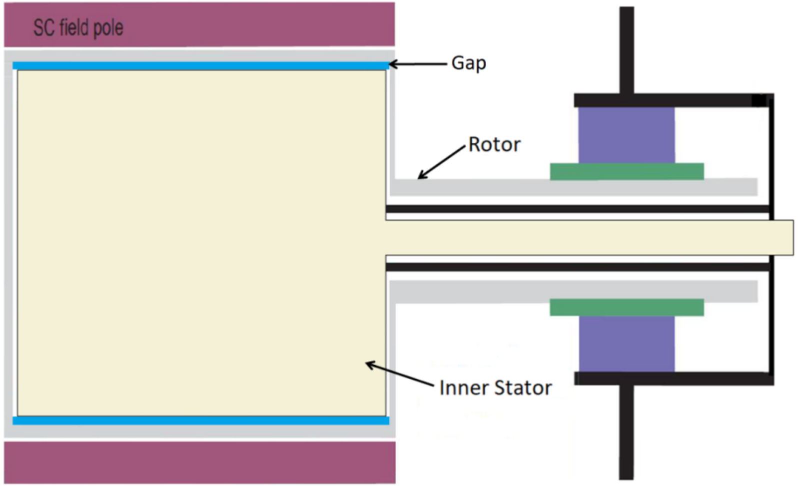
- Cryogen: Gaseous Helium
- Designed by Demaco & UCAM

Rotary Seal

- Ferrofluidic seal
- Being tested

Rotor Cooling System

Rotor Cryostat Reference Model



Rotor – SC Stacks – Rotating

- HT Superconducting stacks
- **Stacks temperature 30K – 35K**

Inner Stator – Stationary

- Cooling fluid
  - Helium
  - Inlet Temperature 25K
  - Operating pressure 2 bar (a)

Gap

- 2 mm high

Required Rotor cooling power: 150 W

- Heat generated in the SC Rotor stacks + heat leak into the system

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Rotor Cooling System

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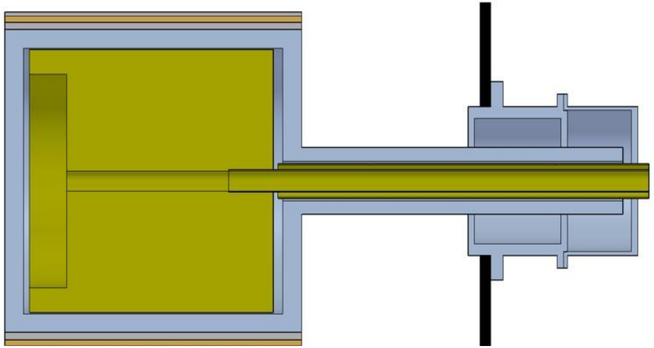
Rotor Cooling Concepts

- Conduction based cooling system: not feasible
- **Convection based system: potential to achieve required cooling power**

Externally Controlled Rotor Cooling System: CONVECTION based system

- Forced Circulation of cooling gas through the system
- Challenging system characterisation:
  - Rotating outer cylinder, ROTOR
  - Stationary inner cylinder, INNER STATOR
  - **Influence of outer cylinder rotation unknown**



Rotor Cryostat Design

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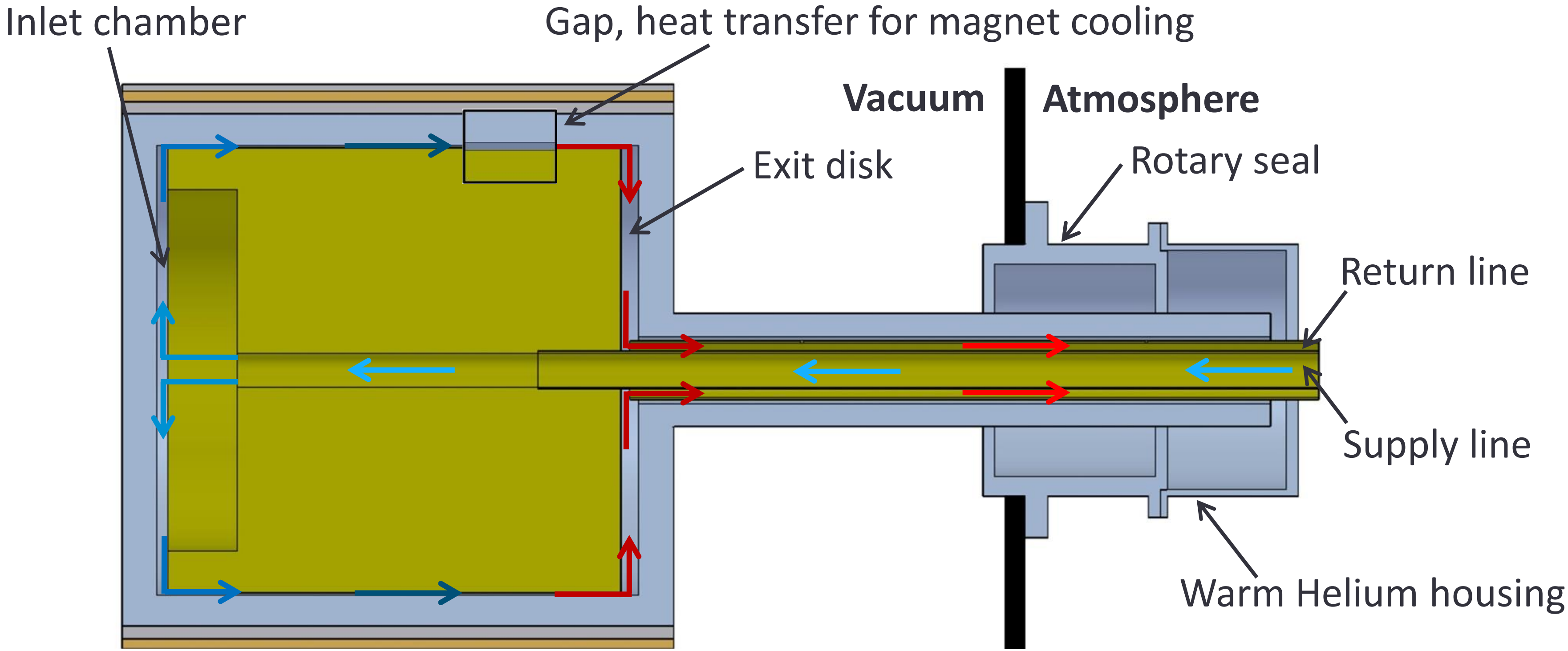
Externally Controlled Rotor Cooling System, forced convection



Heat transfer & flow analysis

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Engineering approach to analyse and size the Rotor Cooling System

- Goal: minimize design risk in an uncertain situation with limited resources

Analysis methods

- General assessment of flow types, literature study
  - Similarities with **Taylor-Couette flow**
- Classical analysis based on Reynolds and Nusselt numbers
  - Flat plate, pipe, **stationary annulus**
- FEM analysis (COMSOL)

Design

- Basic sizing based on worst case results from different kinds of analysis
- Additional measures prepared to improve performance if required

Heat transfer & flow analysis

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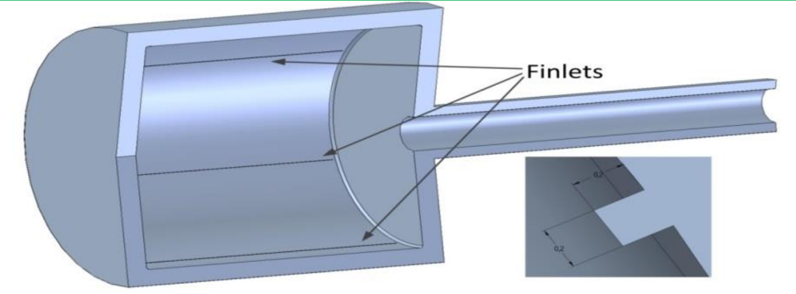
Similarities with Taylor-Couette flow

- Taylor-Couette flow:

  "Flow between independently rotating coaxial cylinders in a closed system"

  - Speciality of University of Twente – Physics of Fluids group
    - Wall roughness important parameter
    - Finlets give remarkable increase of heat transfer (6 in proposed design)



- Standard FEM codes of limited value

Heat transfer & flow analysis

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Classical analysis of forced convection based system

- Turbulent flow: **Re = 14000**
- System characterisation:
  - Rotating outer cylinder, ROTOR
  - Stationary inner cylinder, INNER STATOR
- Literature study to define Nusselt number
  - Cylinders with walls at rest
  - **Influence of outer cylinder rotation unknown**

Geometry	Nu
Flat Plate	70
Pipe	45
Stationary Annulus	35

Nusselt Number = 20

Preliminary heat transfer analysis, forced circulation

Scenario	ΔT (K)	Q_{gap} (W)	Q_{goal} ratio
1	2	41	28 %
2	5	107	71 %
3	10	226	150 %

POTENTIAL TO ACHIEVE REQUIRED COOLING POWER

Heat transfer & flow analysis

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Details for analysis – FEM analysis

- Helium **mass flow** through the system: **20 g/s**
  - From Re = 14000
- **Pressure** in the system: 2 bar(a)

Analysed Cases and Operating modes

Analysis Case	ΔT (K)	Ω (rpm)	
AC 1.1	**2**	**0**	**Magnetisation mode**
AC 1.2	2	1200	
AC 1.3	2	3000	
AC 1.4	**2**	**6000**	**Normal Operation**
AC 2.1	**2**	**6000**	
AC 2.2	5	6000	
AC 2.3	10	6000	

Results: Heat transfer

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Results for analysed Load Cases

Analysis Case	ΔT (K)	Ω (rpm)	Q_{gap} (W)	Q_{goal} ratio
AC 1.1	**2**	**0**	**44**	**30 %**
AC 1.2	2	1200	31	21 %
AC 1.3	2	3000	43	29 %
AC 1.4	**2**	**6000**	**58**	**39 %**
AC 2.1	2	6000	58	39 %
AC 2.2	5	6000	103	69 %
AC 2.3	10	6000	150	100 %

Magnetisation mode

Normal Operation

- **The heat transfer in the gap is determined by the speed of the rotor**
- An **increase of the temperature difference** in the system results in an **increase of the heat transfer**

Results: Flow analysis

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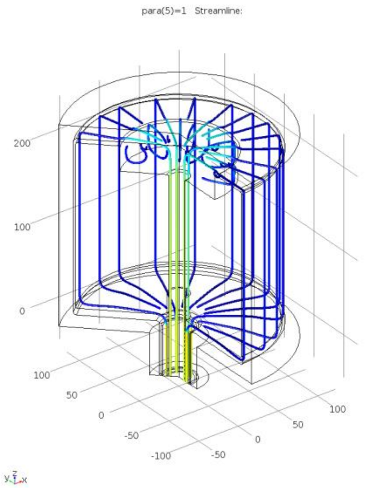
Magnetisation mode

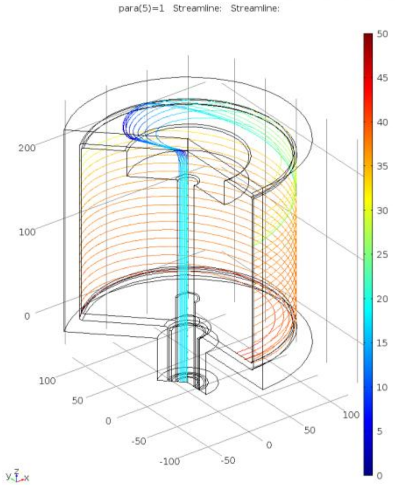
Ω = 0 rpm, ΔT = 2K

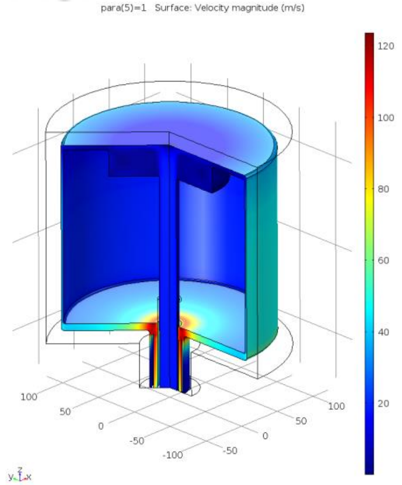
- Pressure flow
- Velocity: axial component
- Pressure drop: 10 mbar



Normal Operation: Ω = 6000 rpm, ΔT = 2K

- Pressure and drag flow: axial and phi components
- Swirl at the exit disk
- Back pressure development
  - Pump effect against flow direction
- Pressure increase in the system: 0.5 bar

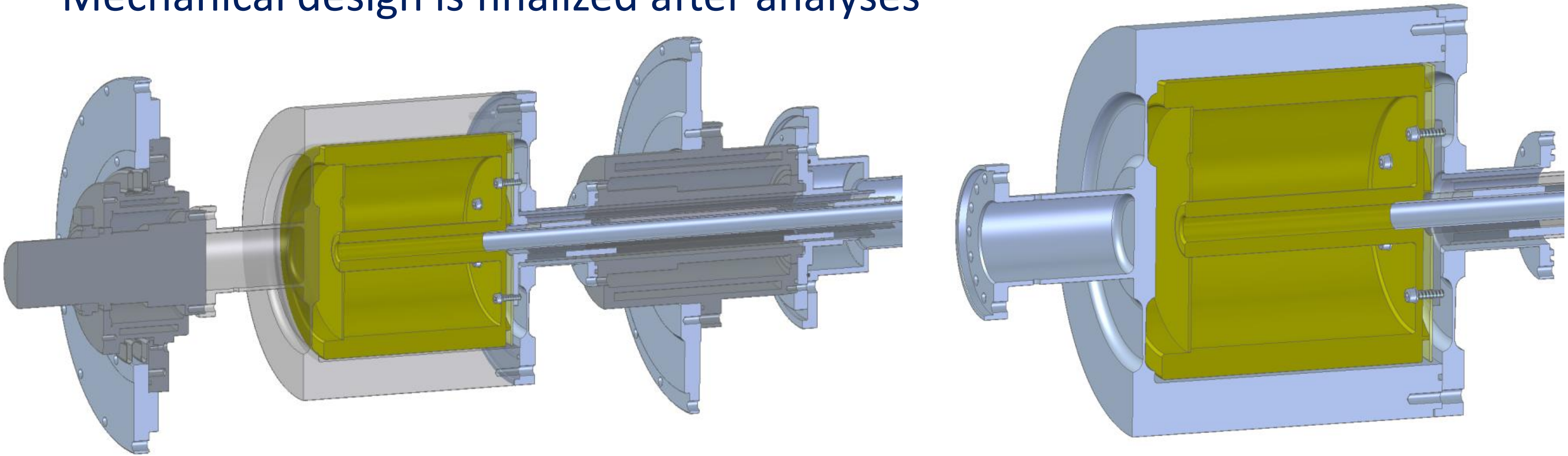




Rotor Cooling System

Conclusions FEM analysis

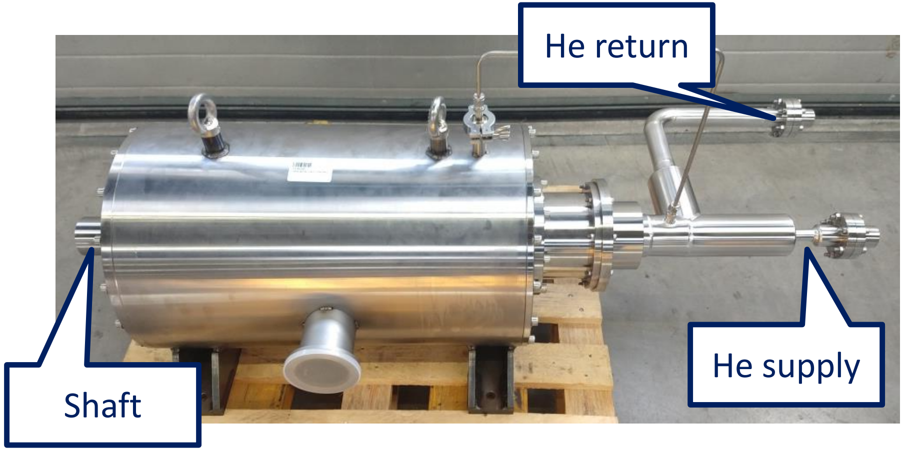
- The Rotor Cooling System
  - Potential to achieve the required cooling power
  - **Experimental validation:** heat transfer and pressure drop
- Mechanical design is finalized after analyses



First test results

First hydrodynamic tests

- Rotor speed up to 800 rpm
- **Very good sealing by ferro-fluidic seals** up to 800 rpm: 10^{-6} mbar/(L.s) level
- More than 1 kW drive power required: significant loss in seals



- No change in pressure drop and flow rate of circulating cooling gas when the rotor speed increases
- **Vortex breaker on exit disk seems effective**

Status and Outlook

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- Continued testing of **Warm Demonstrator**
  - Oswald & Demaco
  - End of the year

- Manufacturing and testing the **Cold Demonstrator**
  - Whole ASuMED consortium
  - First quarter next year

Thank you
for your attention!