Contact information

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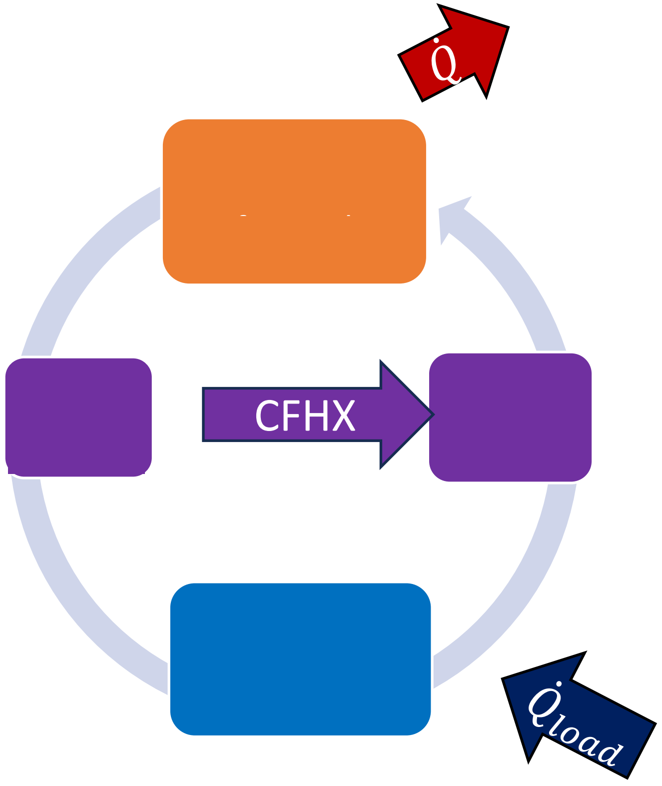
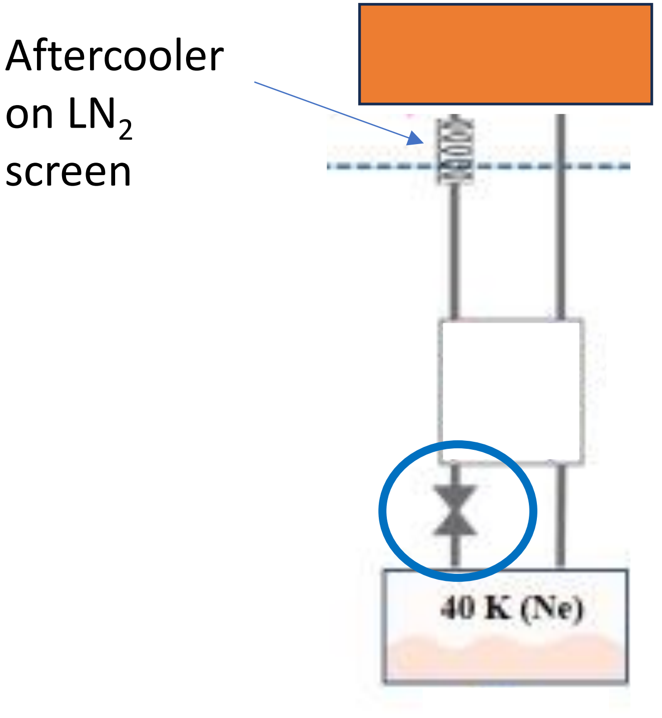
Zero-vibration Sorption Cryocooler for Einstein Telescope

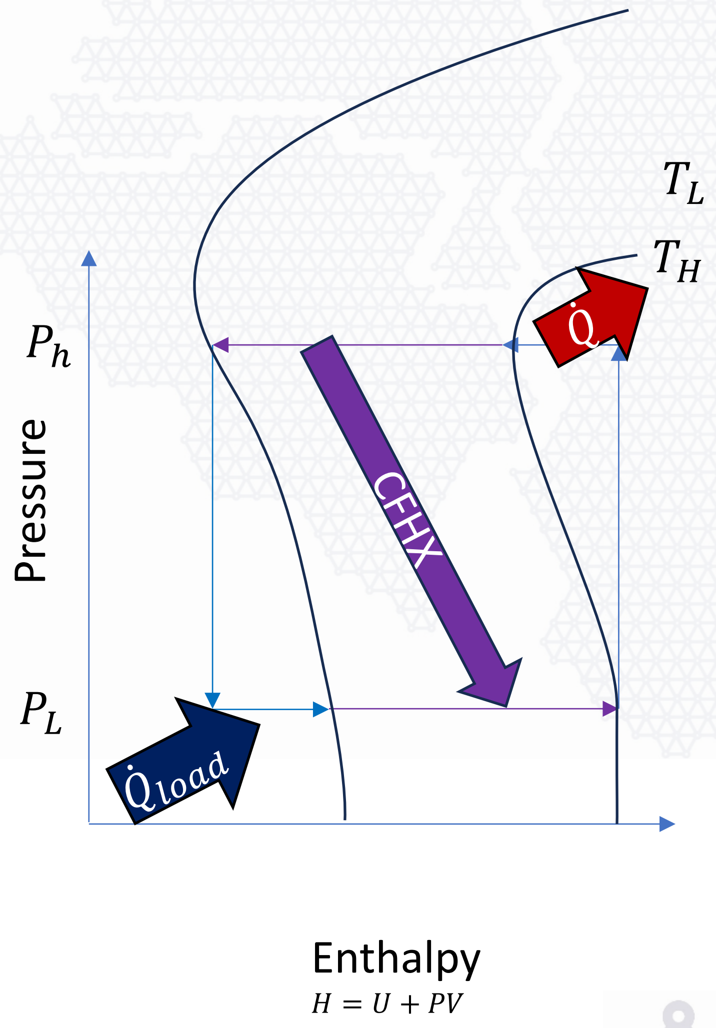
30-09-2025

III Workshop on ET-LF TM Tower Integration, Elba

Joule Thomson cooling

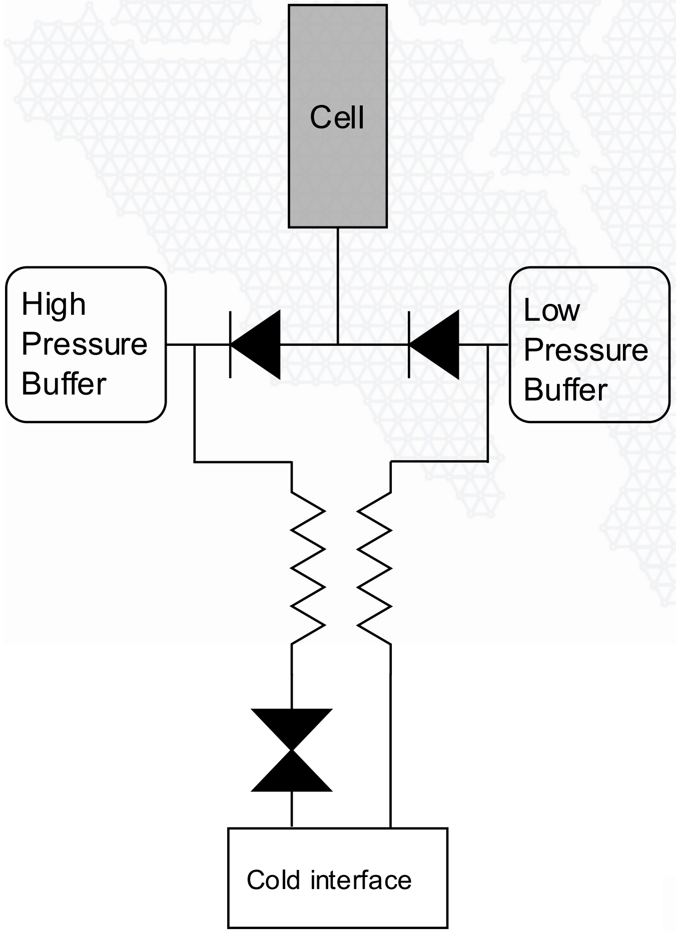






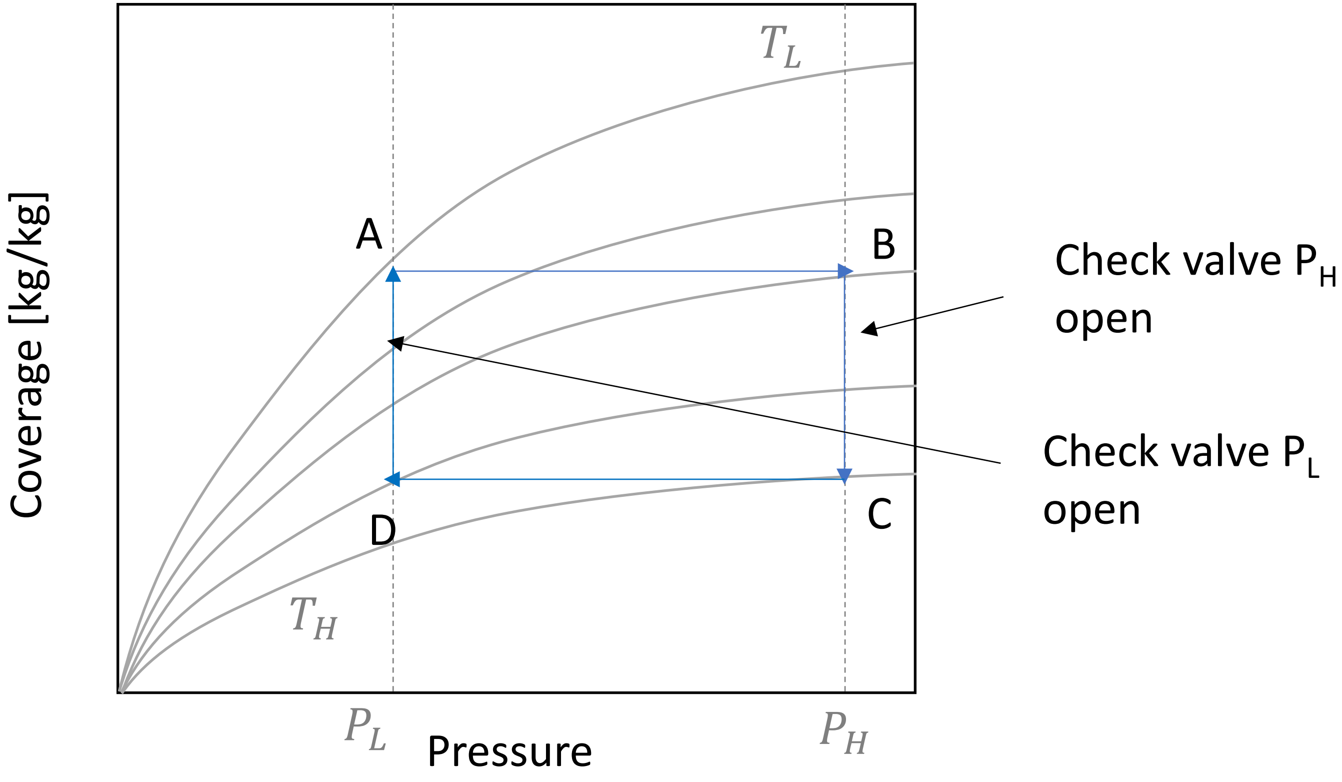
Sorption cooler

- Compression: Sorption cell
- Check valves: turn cell into a pump
- Buffers regulate constant pressure level
- Counter flow Heat Exchangers (CFHX) exchange enthalpy
- Joule Thomson restriction delivers cooling



Sorption cycle

Joule-Thomson cooler with sorption-based compressor



Compression phase: **A → B**
Heater ON

Outflow phase: **B → C**
Heater ON

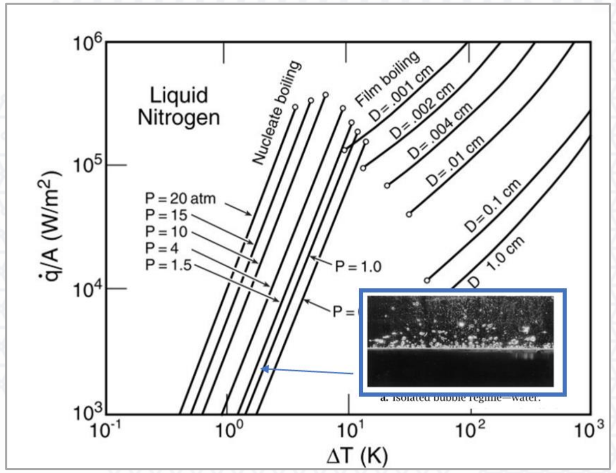
Decompression phase: **C → D**
Heater OFF

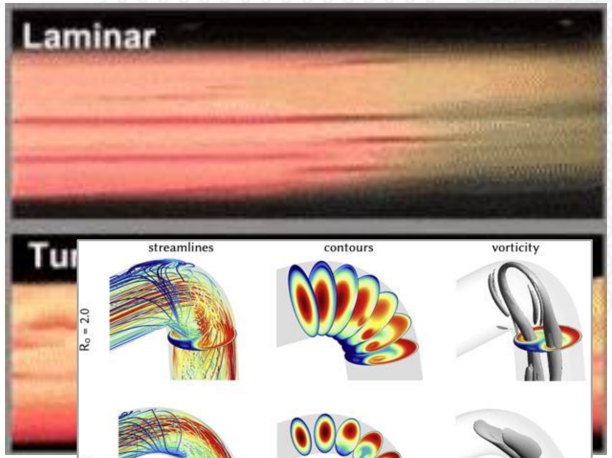
Inflow phase: **D → A**
Heater OFF

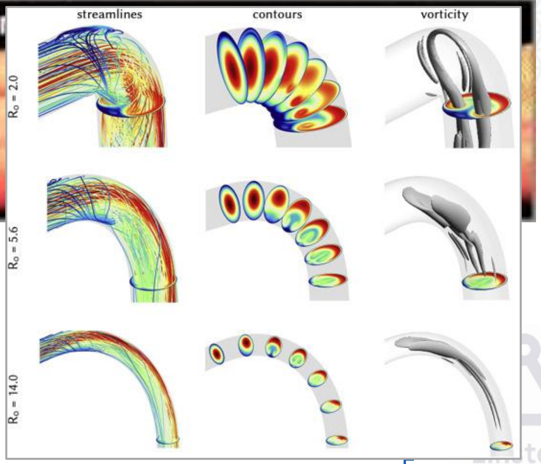
Vibration-free cooling of optical instruments, ET meeting MPI, Marcel ter Brake, Hannover (2013)

Vibration mitigation

- Boiling in transport lines
  → Subcooled LN2
- Boiling in evaporators
  → Large area / wick material
- Unsteady / Turbulent flow
  → Parallelization of Cells and CFHX — Re < 2000
  → Optimize thermo-cycle for low flow. — $\Delta H(p_l, p_h) = \dot{Q}/\dot{m}$
- Secondary flow instabilities
  → Low curvature of tubing — Dean=Re$\sqrt{d/D}$ <60
- Compression vibration
  → Sorption compressor

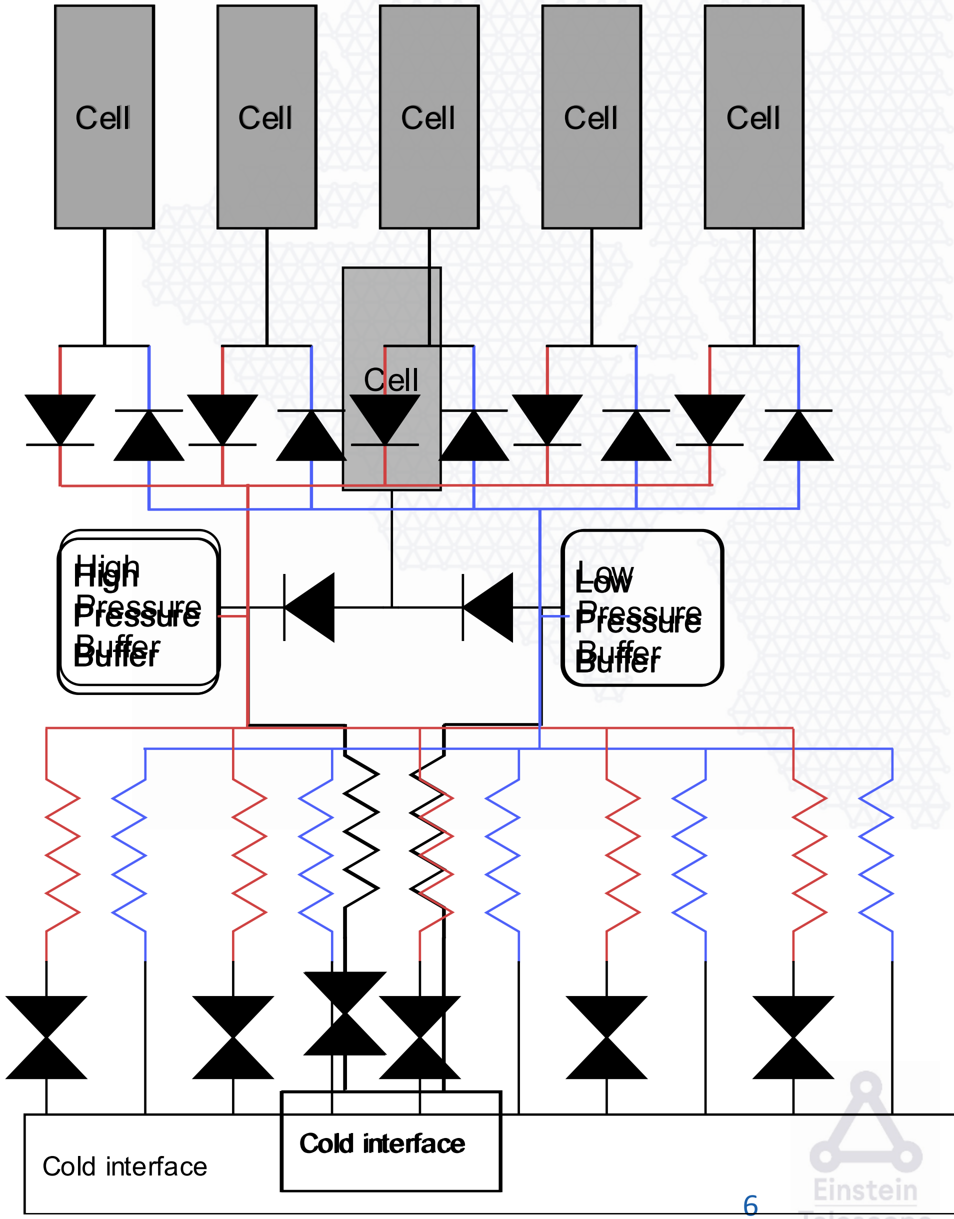




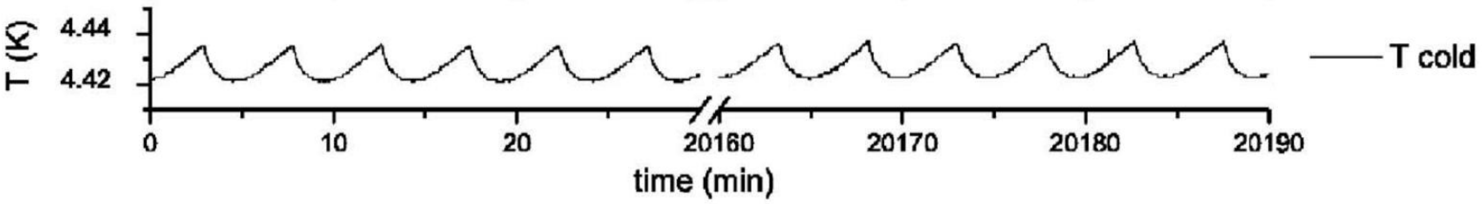


Modular design

- Cells,
- Transport and CFHX
- JT-expanders
- Basically, everything can be made parallel to remain laminar.



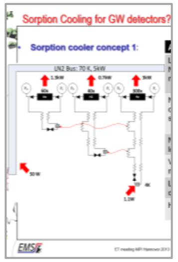
Sorption Cryocooling development at University of Twente



Long-life vibration-free 4.5 K sorption cooler for space applications, J.F. Burger (2007)

1995
TRL 1
University of Twente sorption cryocooler R&D start

2007
TRL 4
ESA Darwin mission 10 mW @ 4.5 K demonstrator

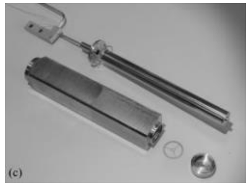


2013
TRL 4
ESA Darwin mission 25 mW @ 14.5 K

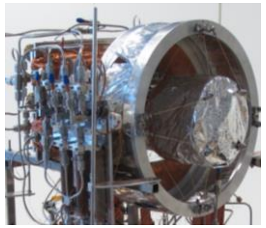
2017
TRL 5
ESA Darwin mission shaker testing

Academic

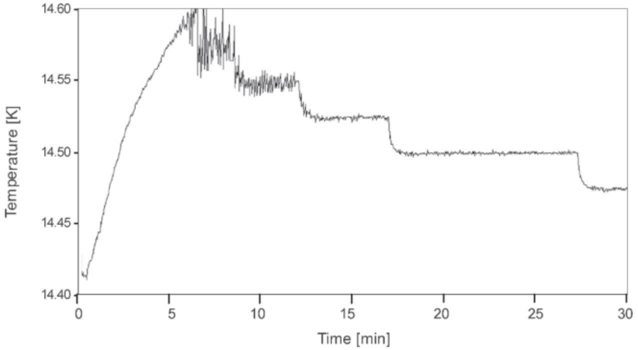
2001
TRL 2/3
Proof-of-concept Sorption cryocooler



2013
Marcel ter Brake presents at 5th ET symposium



2014
TRL 4
METIS on E-ELT 0.4 W @ 8 K



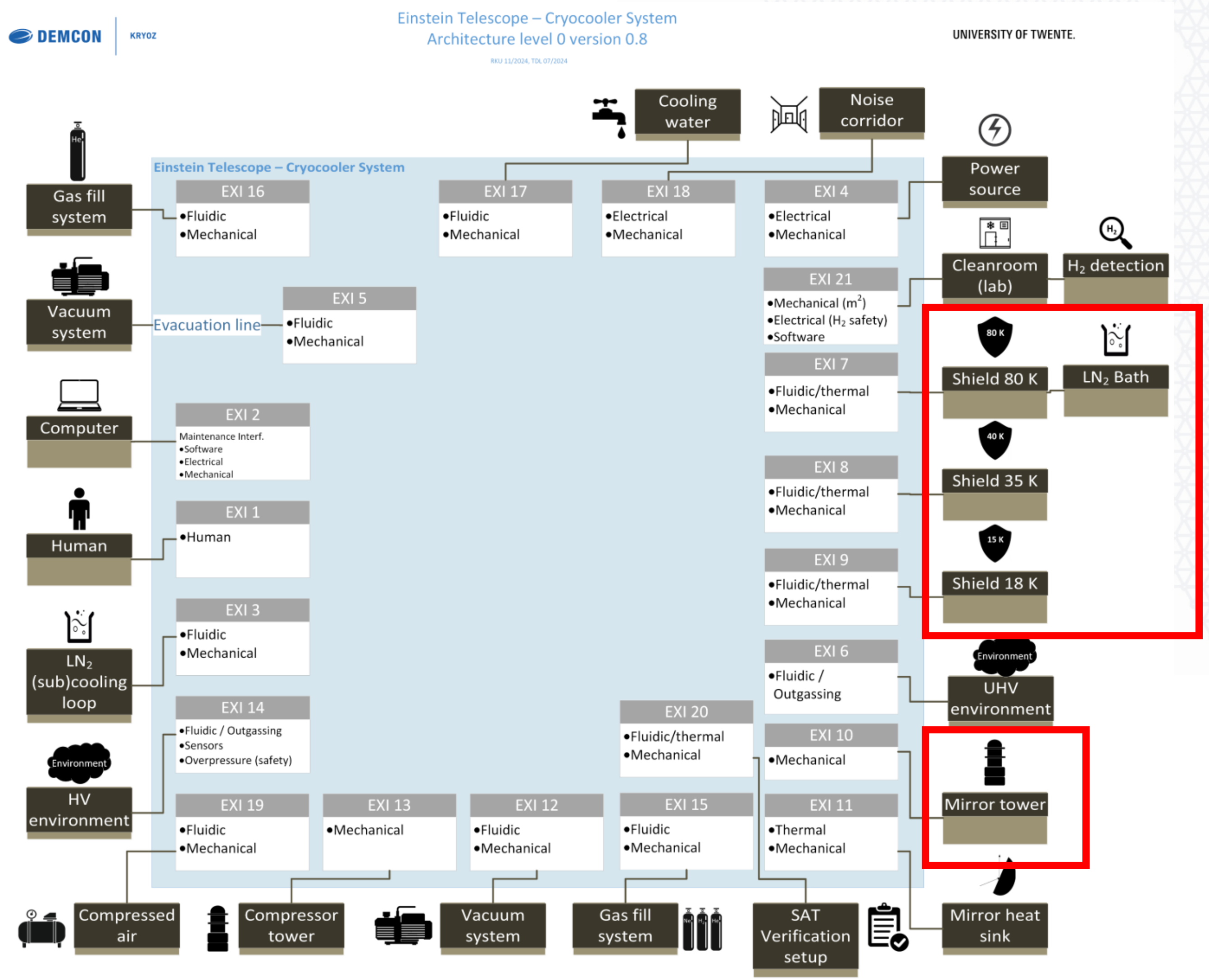
14.5 K Hydrogen Sorption Cooler: Design and Breadboard Tests, M. ter Brake (2011)

Sorption cryocooling for Einstein Telescope pathfinder

Development approach for ETpathfinder

Q1 2024
Requirements definition

Activies
- Systems engineering:
  - Requirement definition
  - Identify external interfaces
  - System architecture

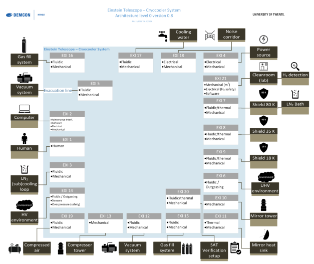


Fabricated external interfaces imposes design constraints

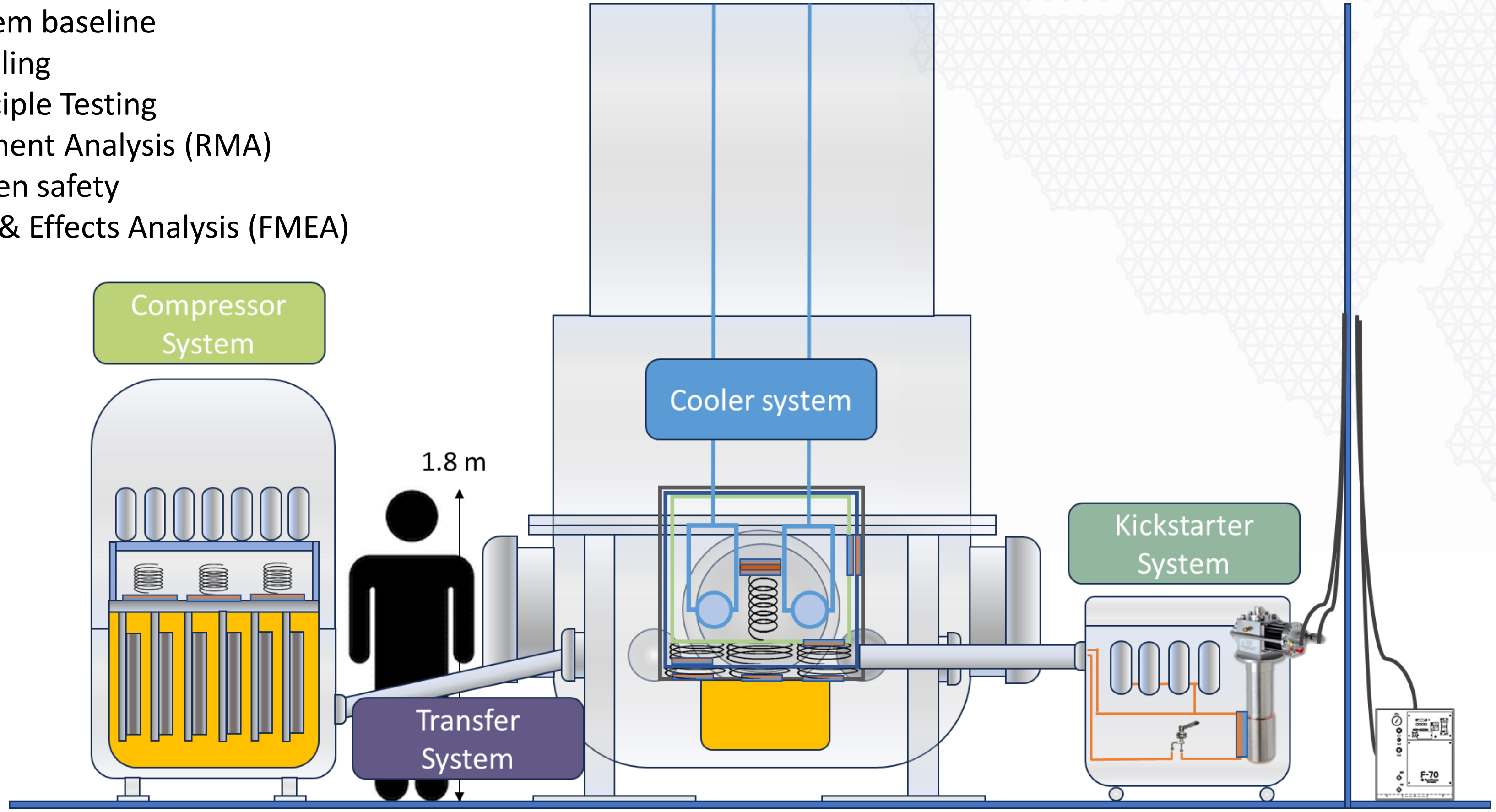
Development approach for ETpathfinder

Activities
- Establish system baseline
- System modelling
- Proof-of-principle Testing
- Risk Management Analysis (RMA)
  - Hydrogen safety
- Failure Mode & Effects Analysis (FMEA)

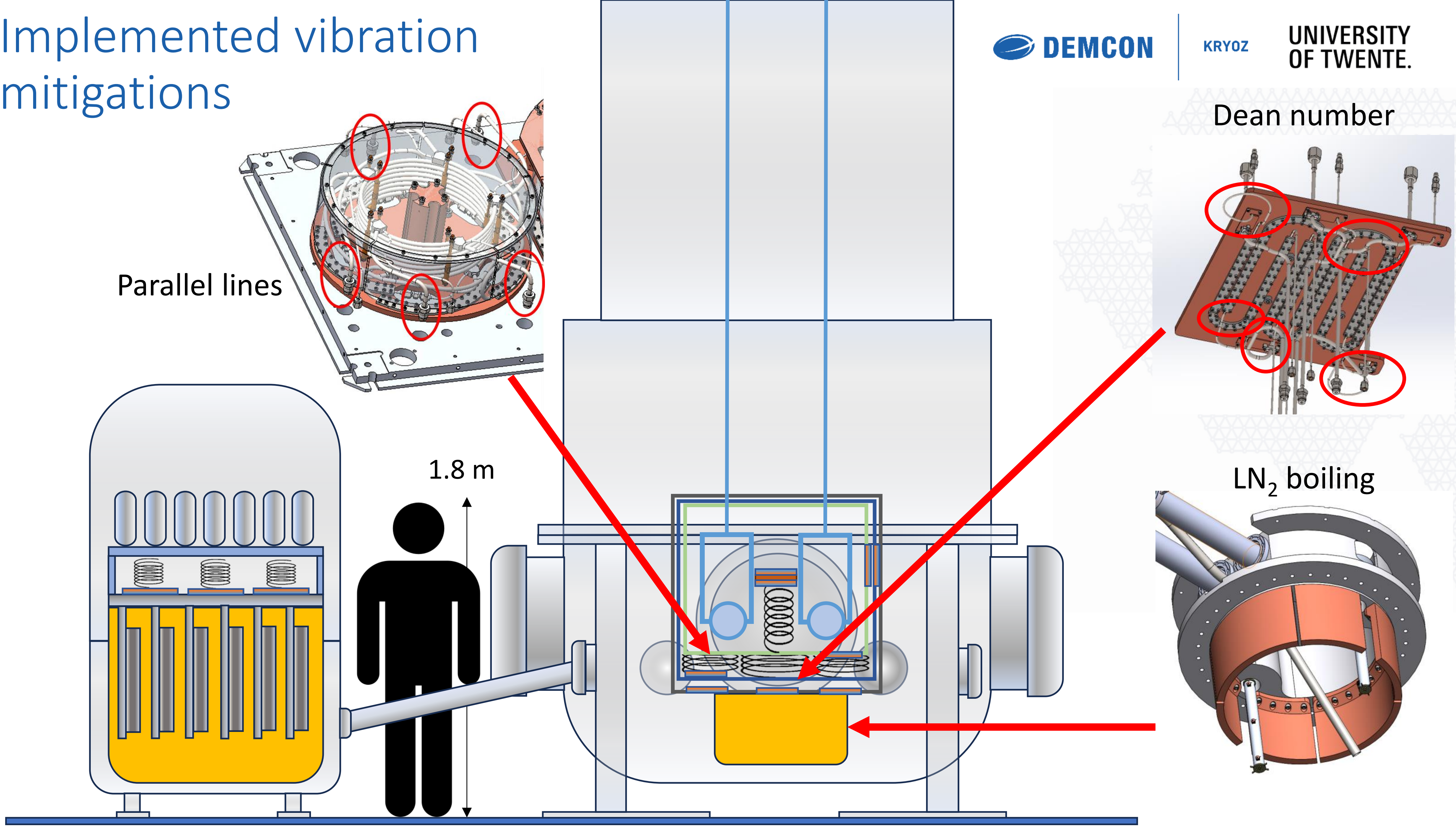
Q1 2024
Requirements definition



Q3 2024
Completion Concept Design

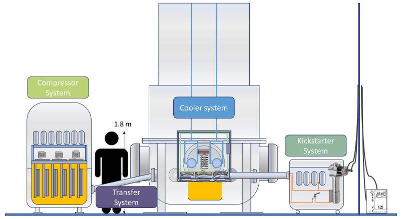


Implemented vibration mitigations

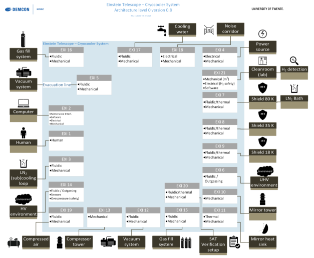


Development approach for ETpathfinder

Q1 2024
Requirements definition

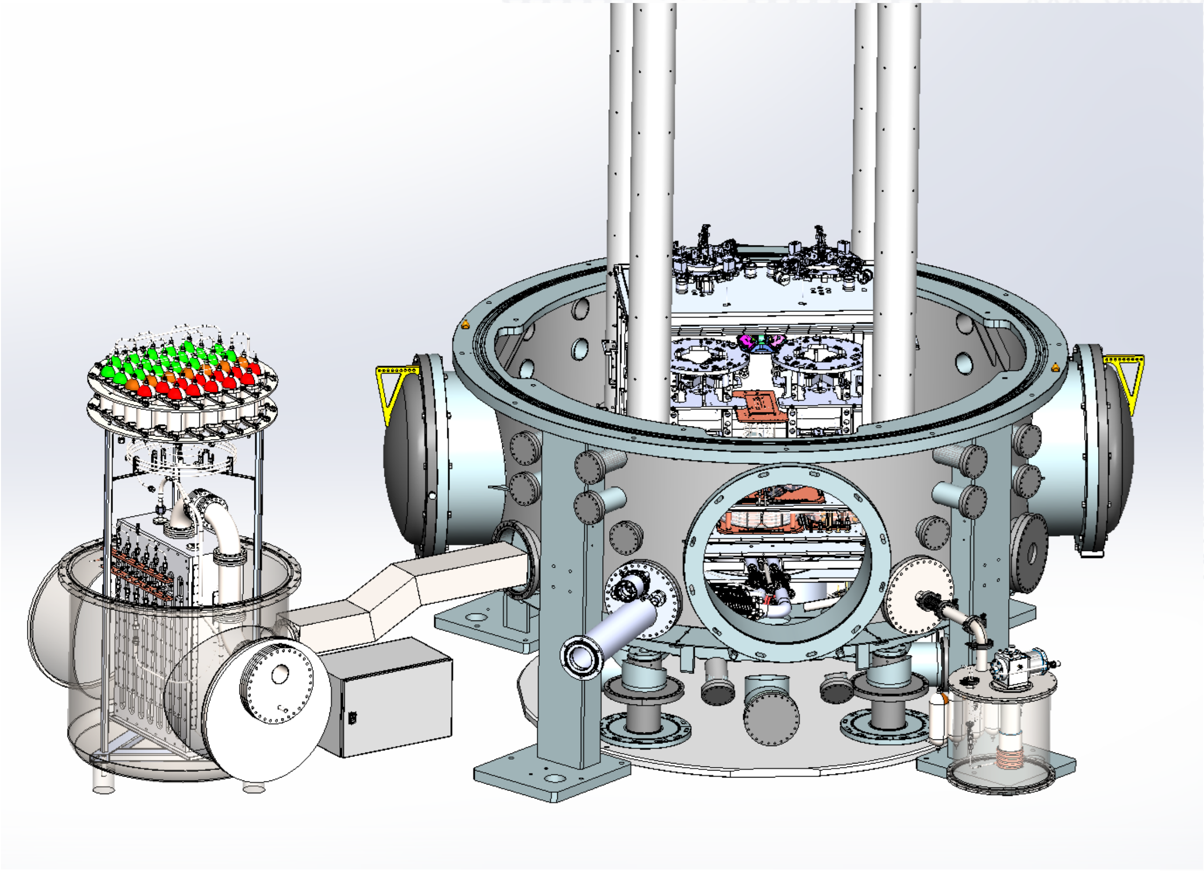


Q2 2025
Completion Detailed Design

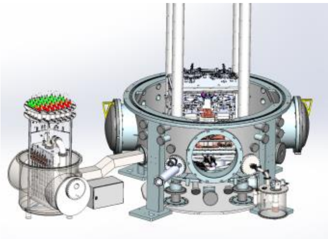


Q3 2024
Completion Concept Design

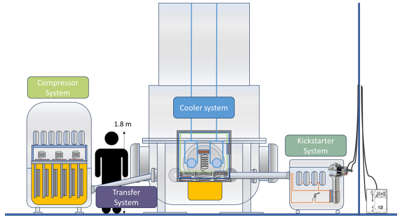
Activities
- CAD-drawings
- Component selection
    - Cryo & UHV compatible



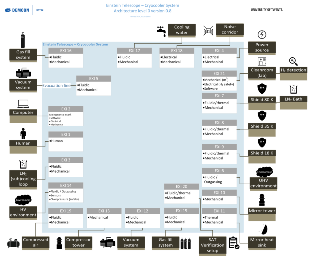
Development approach for ETpathfinder



Q1 2024
Requirements definition



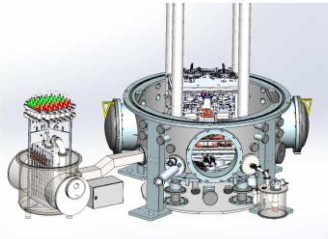
Q2 2025
Completion Detailed Design



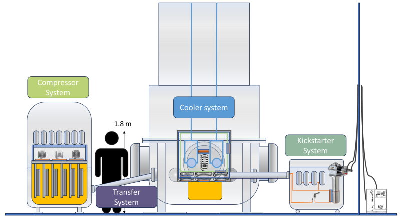
Q3 2024
Completion Concept Design

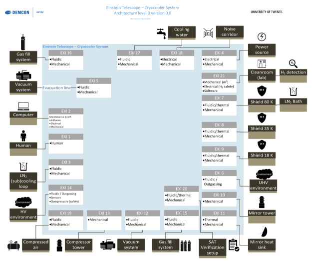
Q2 2025
Burst testing
(tested >430 bar, required: 100 bar)
Lifetime testing
(tested >1M cycles, required: 275k cycles)

Development approach for ETpathfinder



Q1 2024
Requirements definition





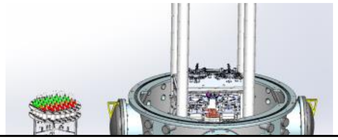
Q3 2024
Completion Concept Design

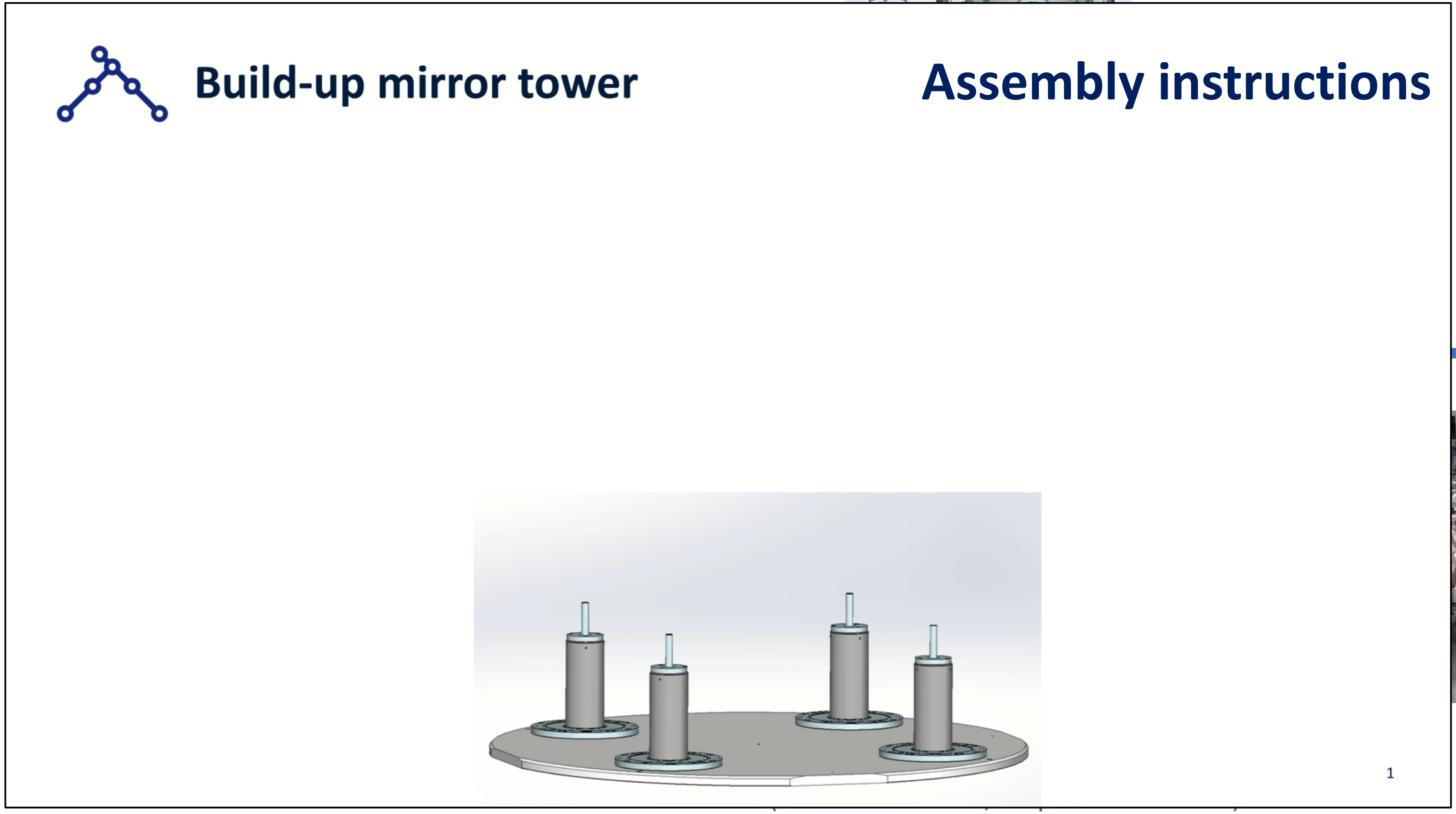
Q2 2025
Completion Detailed Design

Q4 2025
Complete integration at University of Twente

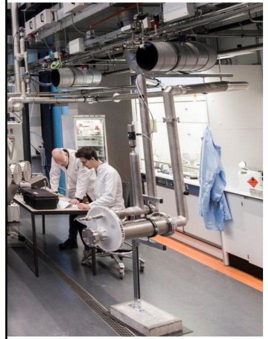
Q2 2025
Burst testing
(tested >430 bar, required: 100 bar)
Lifetime testing
(tested >1M cycles, required: 275k cycles)

Development approach for ETpathfinder





[Click here for the link of the gif]



Q4 2026
Complete integration & verification at ETpathfinder

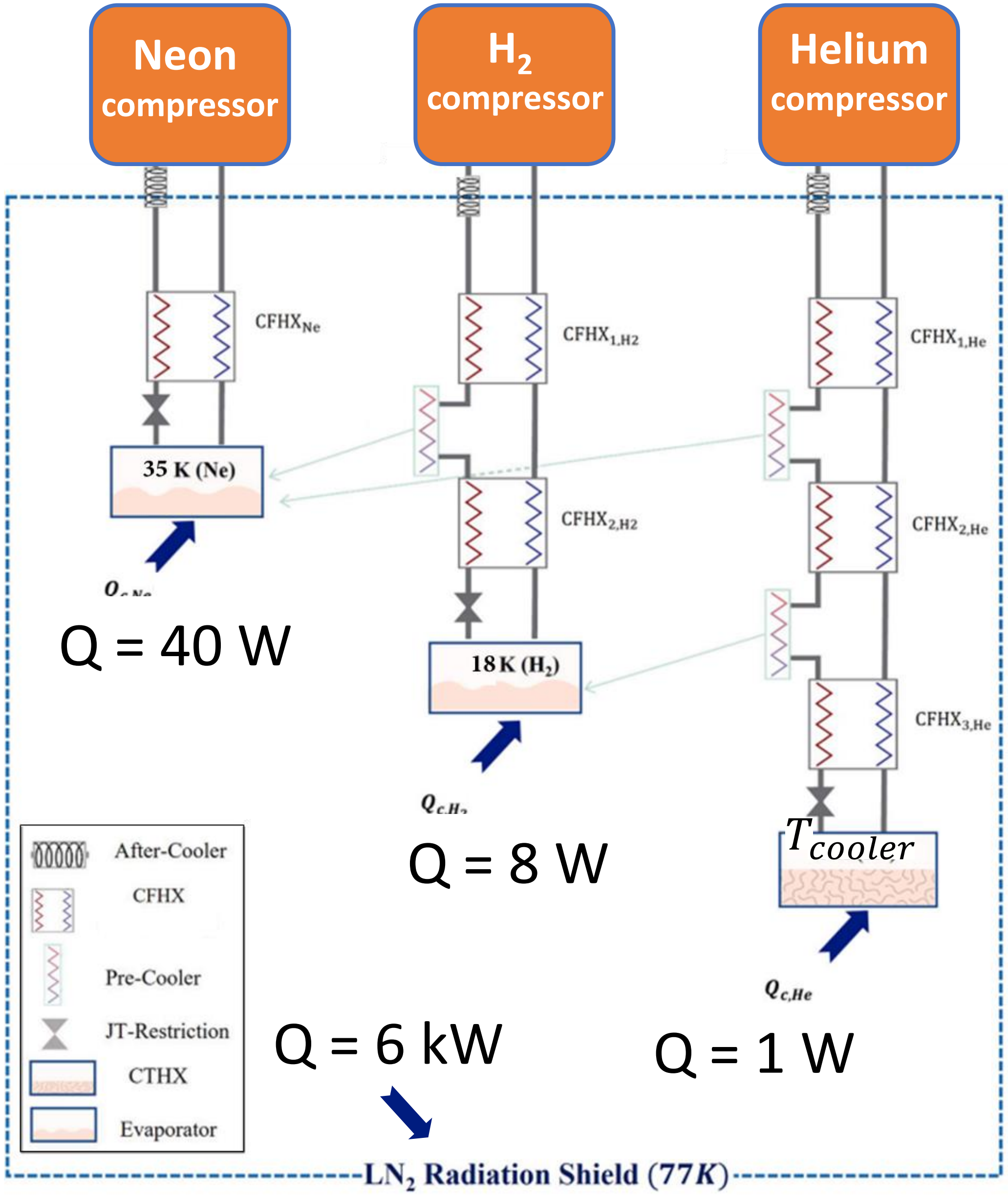
Lifetime testing
(tested >1M cycles, required: 275k cycles)

Sorption cryocooling for Einstein Telescope

Concept desig ET

- Scalable design, able to cool Einstein Telescope mirrors

- T_{cooler} =
  5.3 – 15K
  (single phase He)
  3.5 – 5.3 K
  (two-phase He)



T_{cooler}
Trade-off between thermal noise and mechanical noise.

Colder does not imply better: non-linear k of Al

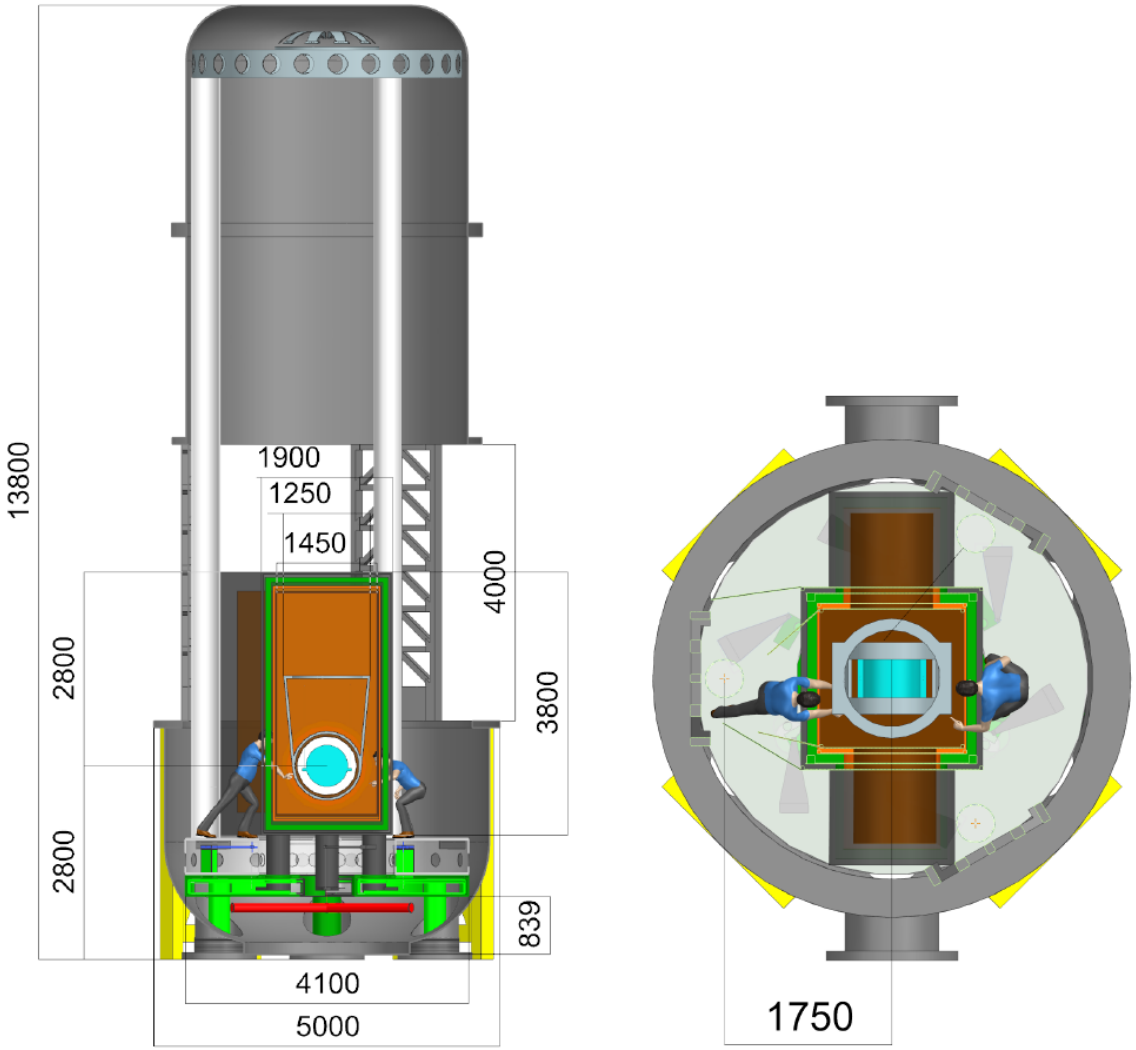
$$\frac{\dot{Q}L}{A} = \int_{T_{cooler}}^{T_{platform}} k(T)\,dT$$

Mirror vibr. lvl → $T_{platform}$
Decoupling criteria → $\frac{L}{A}$

Supporting_Document_for_The_ET_Baseline_Detector_Layout, p. 83-88, Henk Jan Bulten (2025)
Vibration-free cooling of optical instruments, ET meeting MPI, Marcel ter Brake, Hannover (2013)

Integration in Einstein Telescope: tower

- Counterflow Heat Exchangers can be placed anywhere between the shields.
- Warm feedthroughs at vacuum wall
- Gas Helium loop with dedicated heat exchangers for cooldown.



Supporting_Document_for_The_ET_Baseline_Detector_Layout, p. 83-88, Henk Jan Bulten (2025)

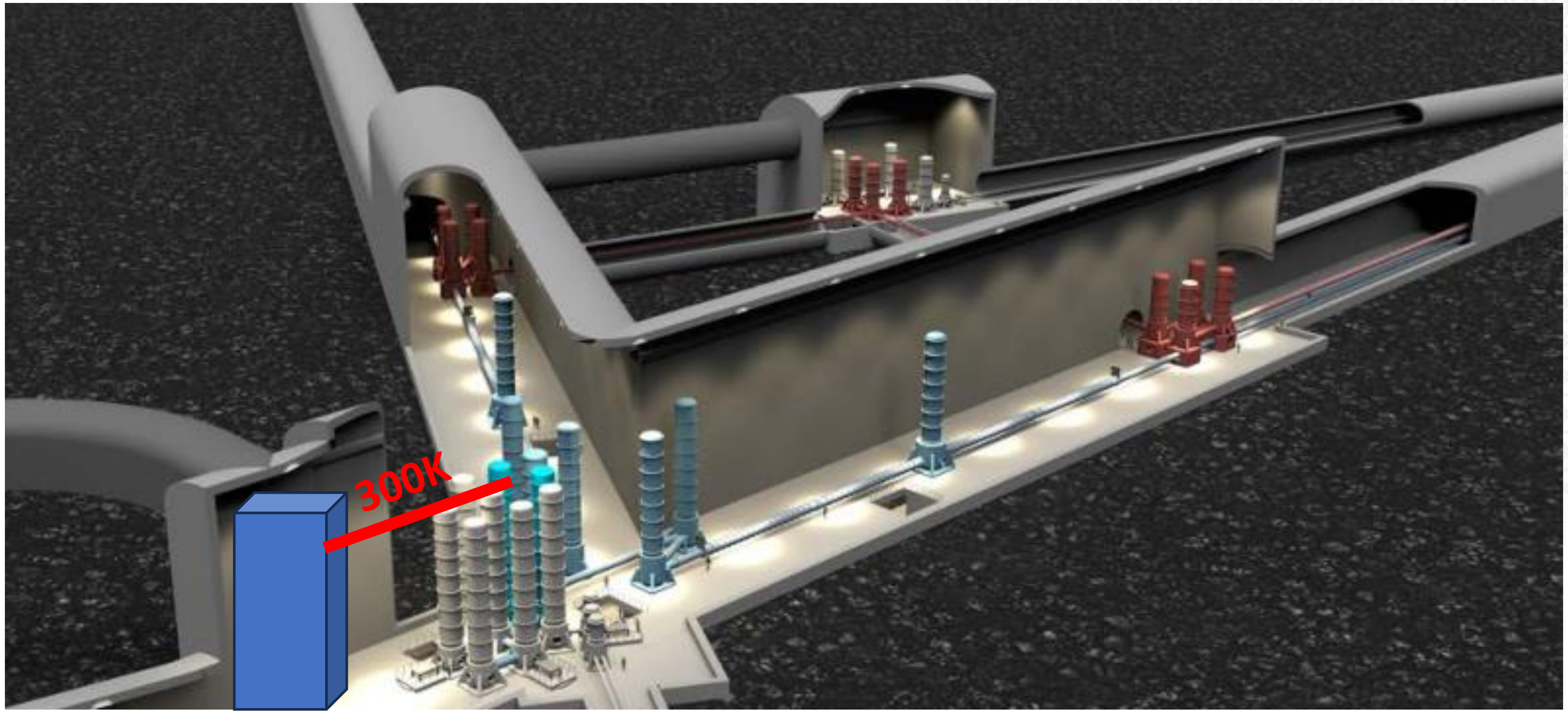
Integration in Einstein Telescope: facility

Compressor:

- ETPF: 1 m^3 for 50 mW at 8K
  →ET: 20 m^3 per 1W at 8K

Low quality vacuum (HV: 10^{-4} mbar)

Warm transfer lines allow for flexible placement of compressor



Key take-aways

Sorption-based JT-cryocooling has unique properties for ET:

1. The system optics are cooled with a low, laminar gaseous Helium mass flow, minimizing potential vibrations
   - LN2 backend cooling source allows for a low Helium mass flow close to the optics
2. No actively moving components
   - Low vibration
   - Low maintenance/high reliability, essential for continuous operation for a large-scale underground observatory
3. The sorption compressor design is scalable to meet cooling requirements ET
4. Compressor and Cooler transfer gas lines operated at room temperature
   - Flexibility in tube length
5. No interfacing with suspension framework necessary
   - Required volume budget fits in radiation shields
6. System is designed to be Fluid-Induced Vibrations neutral
7. Cooldown within 7 days for ETpathfinder, 9 days for ET
8. High TRL (6/7 in 2026, aim: 9 in 2035)
   - Technology benchmarking in ETpathfinder facility in 2026/2027

"It is our ambition to demonstrate the technical readiness and low-displacement noise performance of sorption-based Joule-Thomson cryo-cooling for Einstein Telescope"

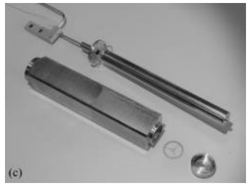
Roadmap sorption cryocooling for Einstein Telescope

Academic

1995
TRL 1
University of Twente sorption cryocooler R&D start

2007
TRL 4
ESA Darwin mission 10 mW @ 4.5 K demonstrator

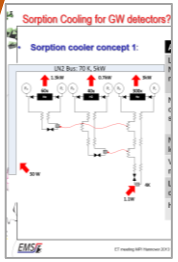
2001
TRL 2/3
Proof-of-concept Sorption cryocooler



Industrialization

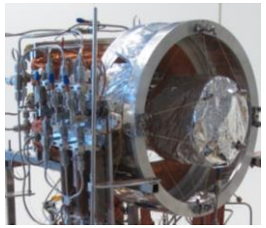
2009
Cooll founded by Johannes Burger

COOLL



2013
TRL 4
ESA Darwin mission 25 mW @ 14.5 K

2013
Marcel ter Brake presents at 5th ET symposium



2018
TRL 6
Sorption system prototype

2014
TRL 4
METIS on E-ELT 0.4 W @ 8 K

2024
TRL 9
Sorption domestic system

2017
TRL 5
ESA Darwin mission shaker testing

Industrialization

KRYOZ technologies

2008
Kryoz founded by Pieter Lerou

2014
TRL 6
Sorption cryocooler for Telecom

DEMCON | KRYOZ

2016
Kryoz joins Demcon Group

2021
TRL 9
JT crycooler

COOLL UNIVERSITY OF TWENTE.
DEMCON | KRYOZ

2024
Cryo consortium is formed

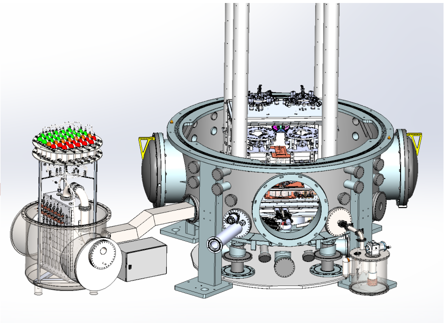
Sorption technology & Industrial supply chain qualified for ET

Academic to Industrialization

?

2026
TRL 6/7
Technology fully proven in ETpathfinder

2035
TRL 9
Technology implementation in ET



Thank you!

Contact information

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Cooll:
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"It is our ambition to demonstrate the technical readiness and low-displacement noise performance of sorption-based Joule-Thomson cryo-cooling for Einstein Telescope"

UNIVERSITY OF TWENTE.

DEMCON | KRYOZ

COOLL

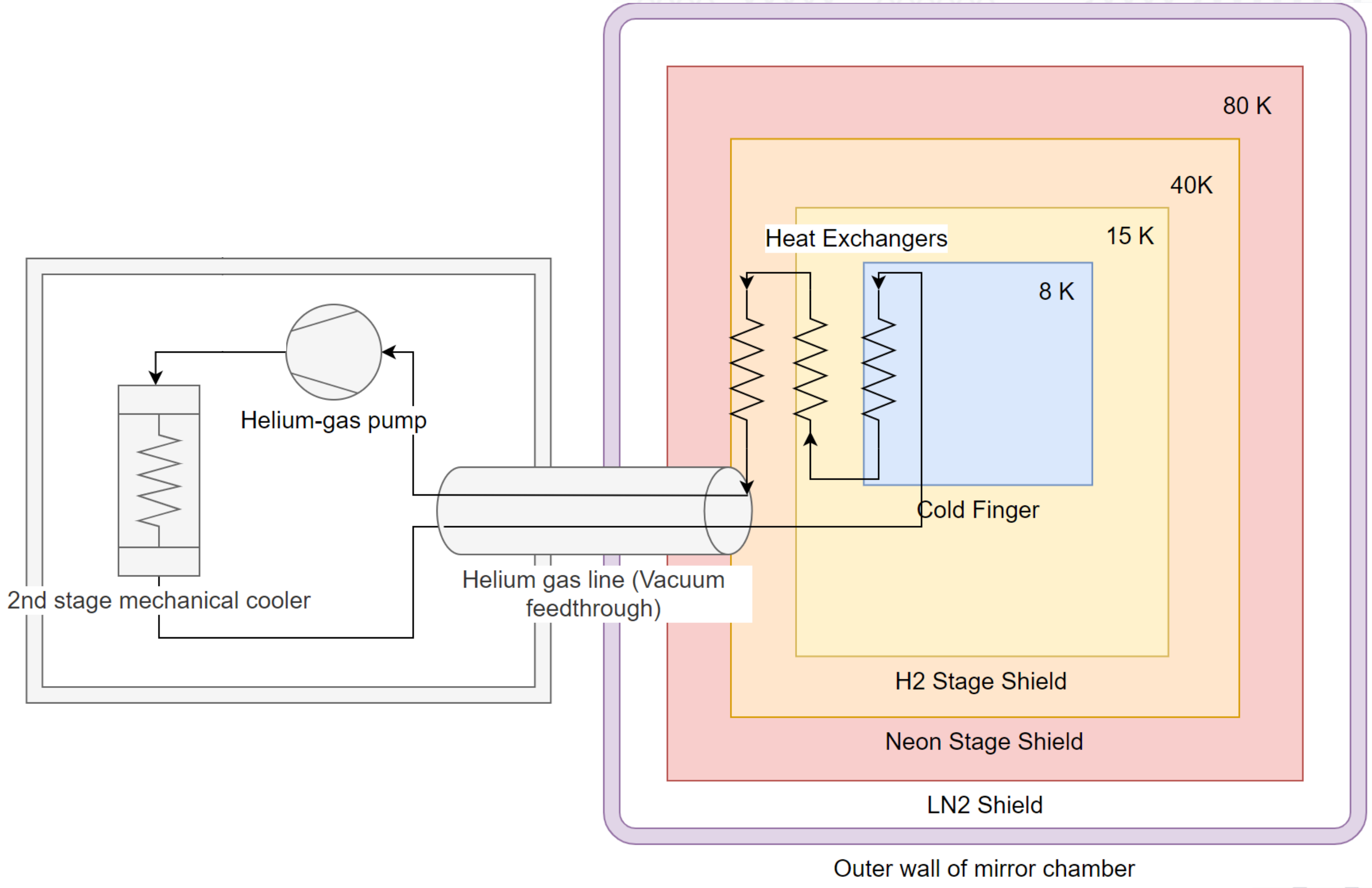
Back-up slides

Kickstarter system $\partial_t T \ll 0$

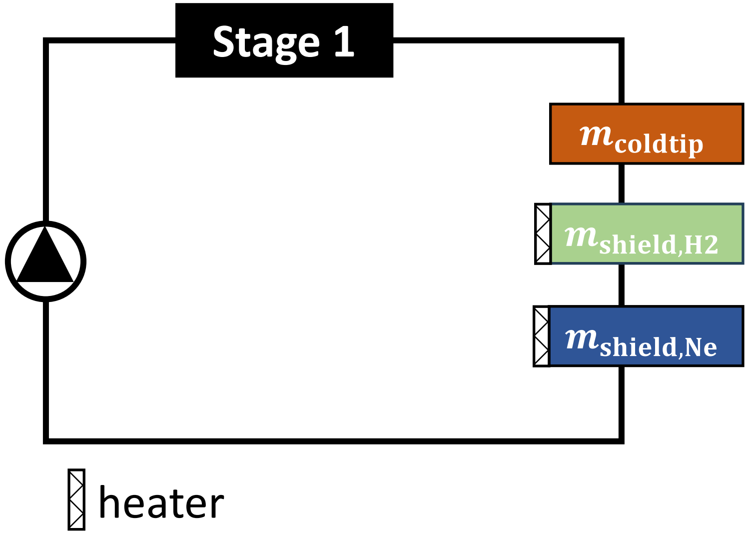
Heat exchanger on all stages

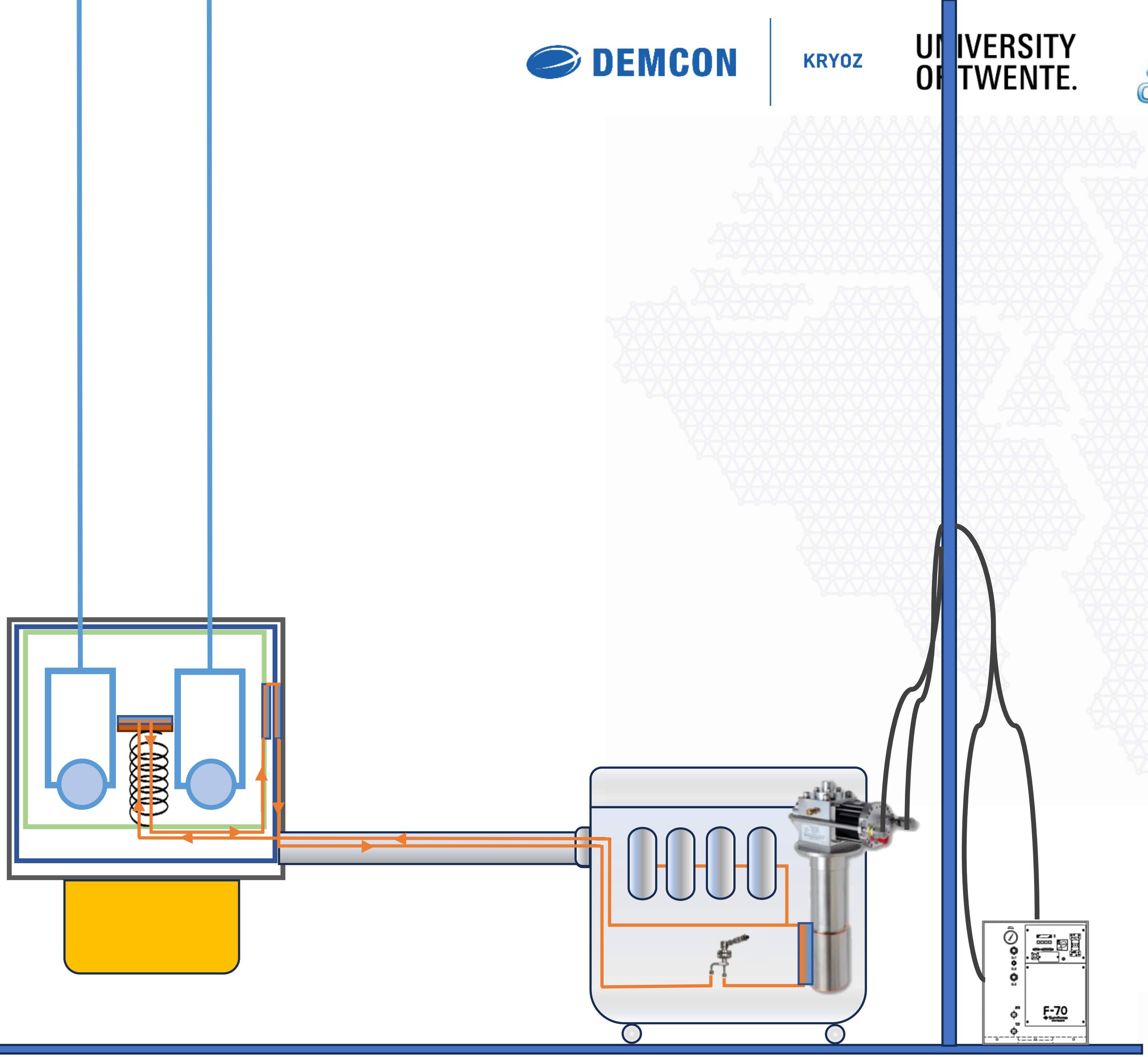
Cold He gas is circulated

Coldest interface 'cold finger'

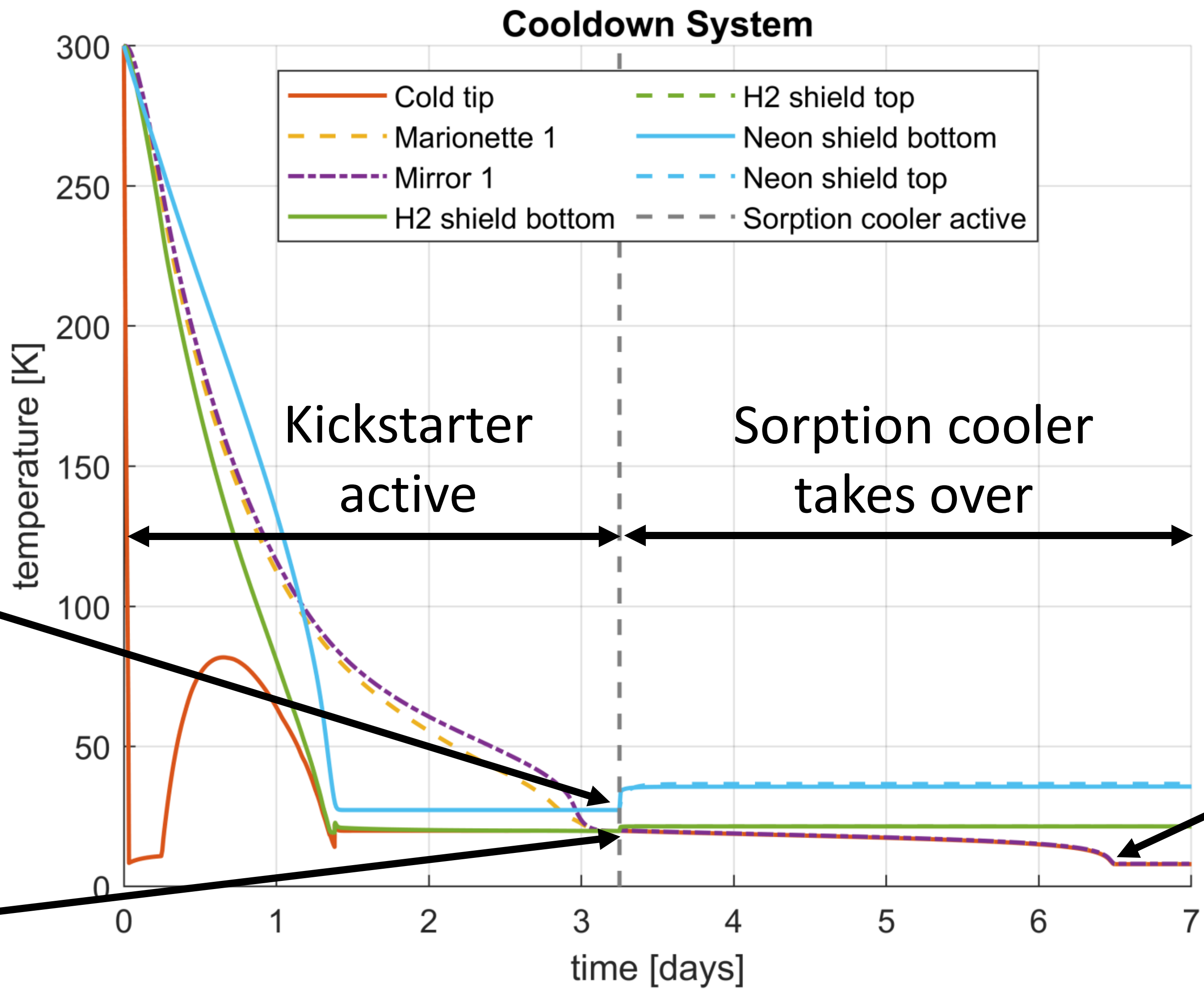


Kickstarter





Cooldown ETpathfinder



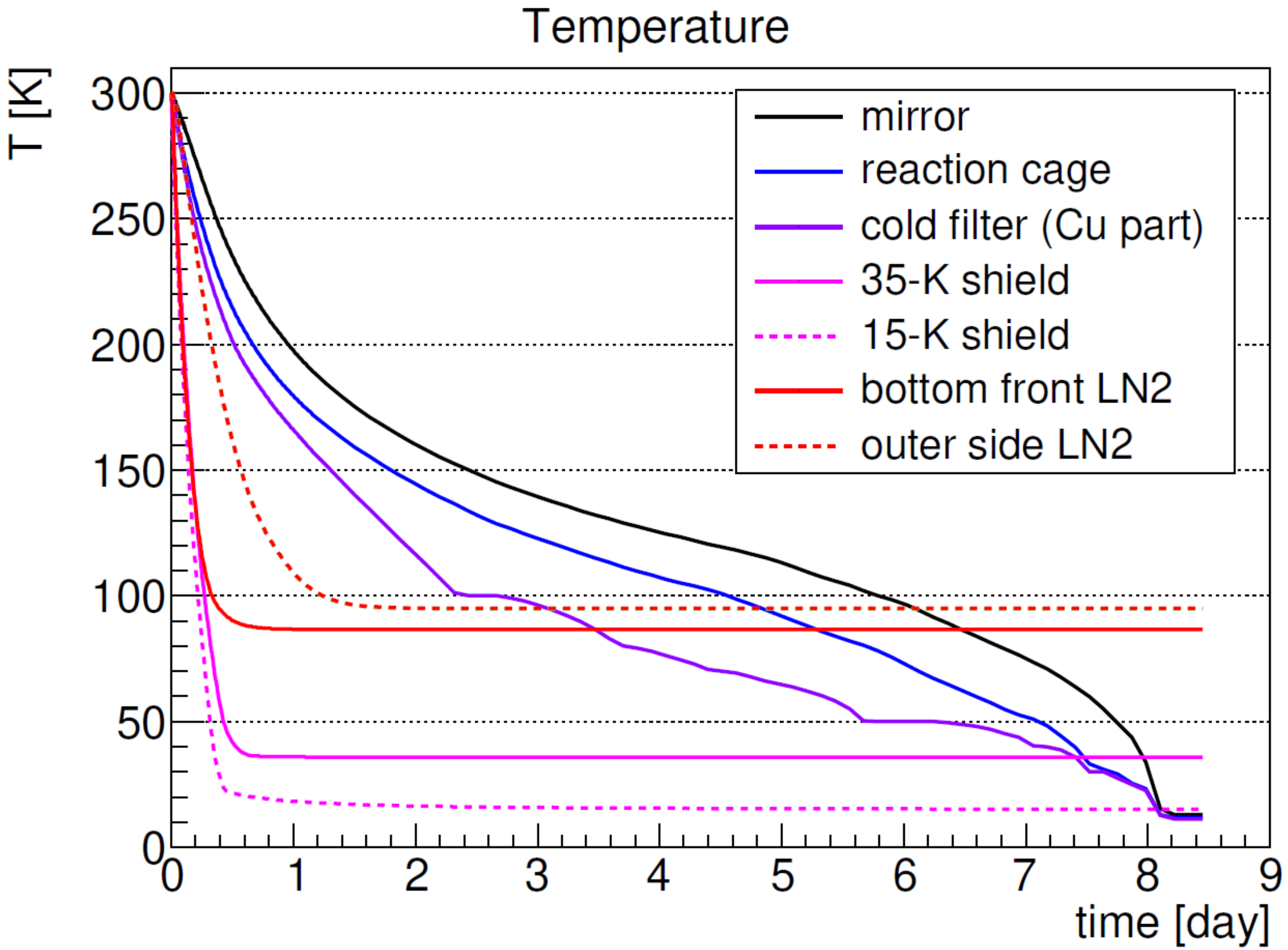
Total cooldown: 6.5 days
Requirement: 4 weeks

Heater prevents freezing of neon

Cold tip reaches 20 K

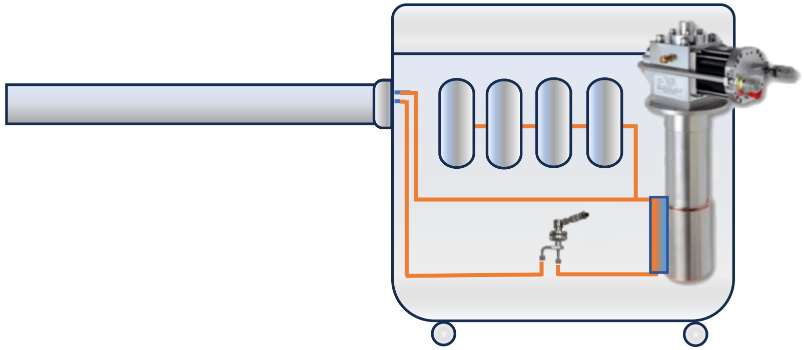
Cold tip reaches 8 K

Cooldown Einstein Telescope

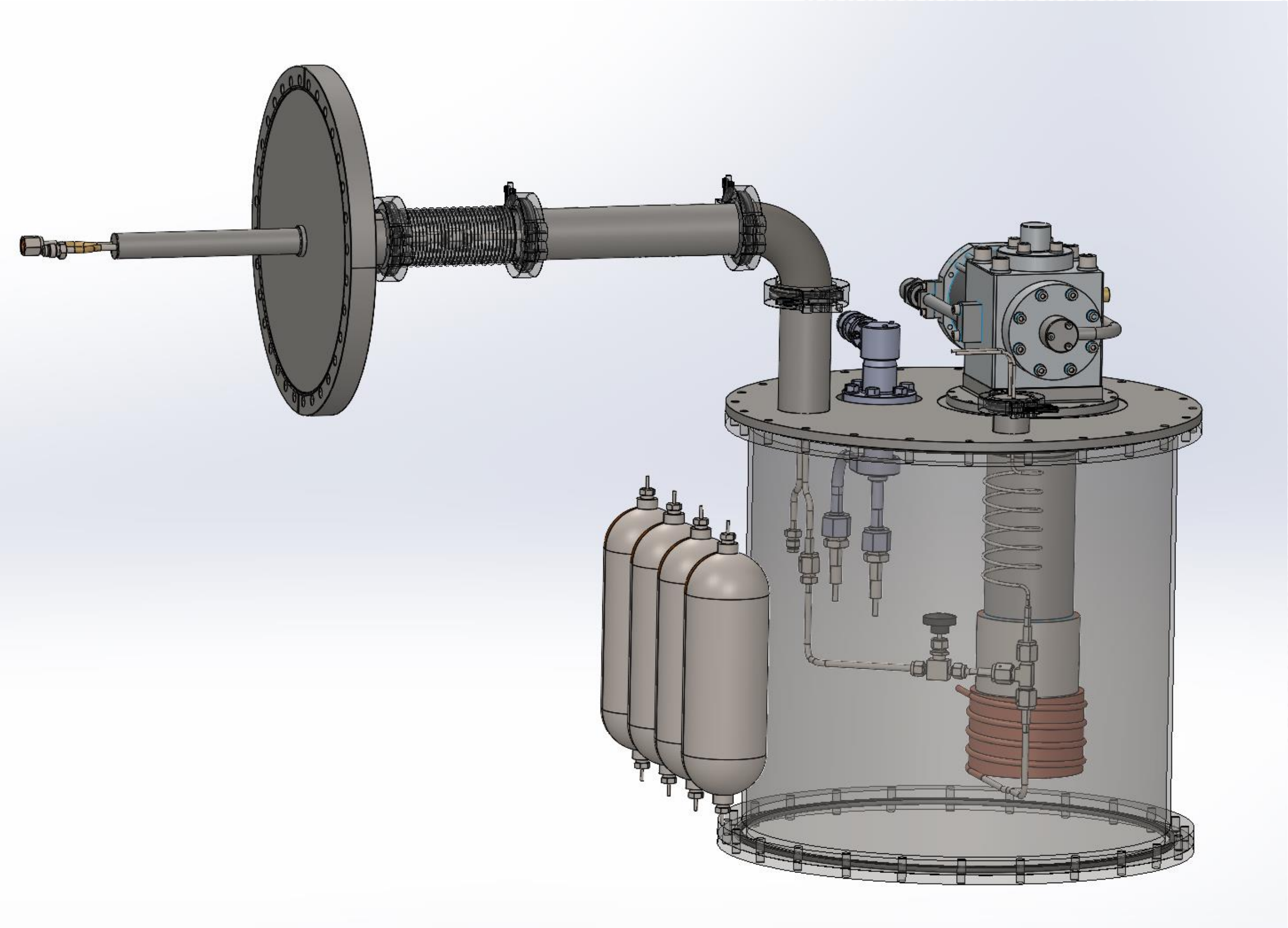


Supporting_Document_for_The_ET_Baseline_Detector_Layout, p. 83-88, Henk Jan Bulten (2025)

Kickstarter

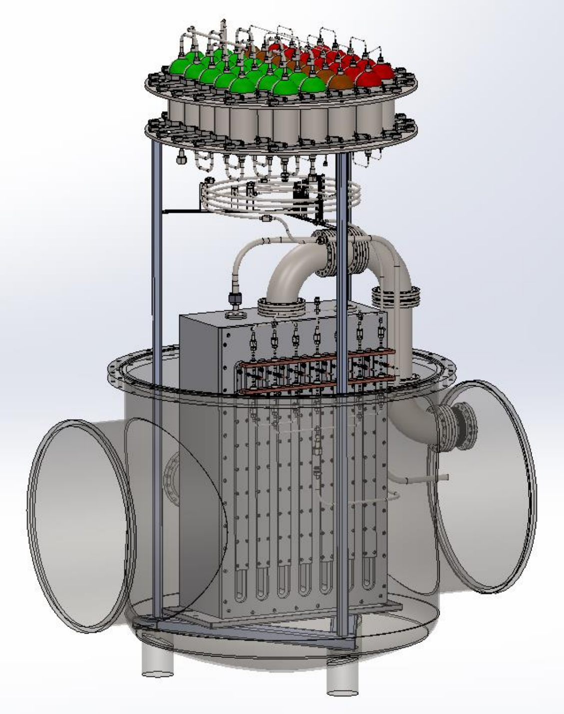


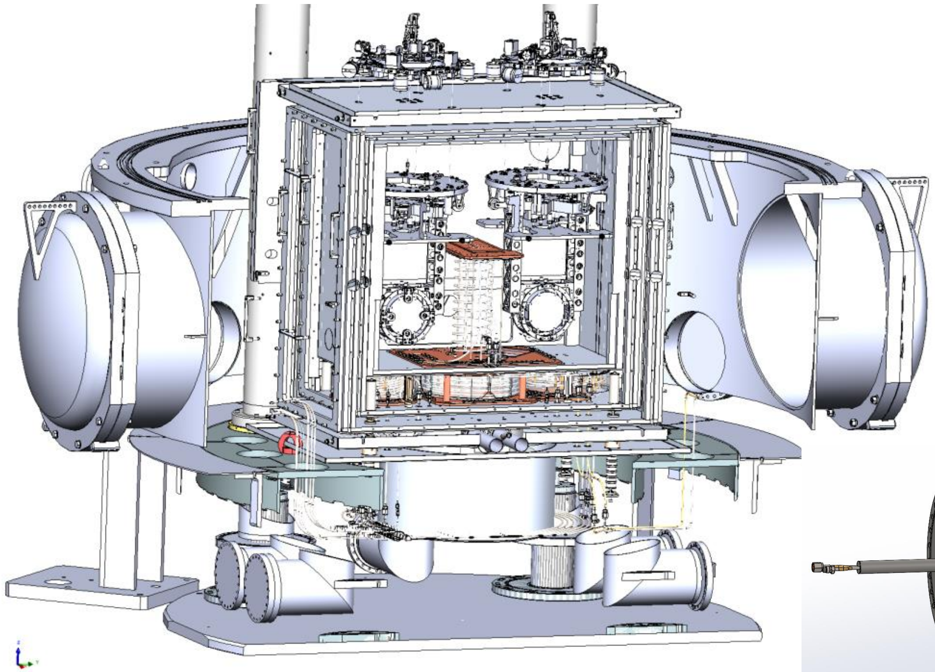
Concept design

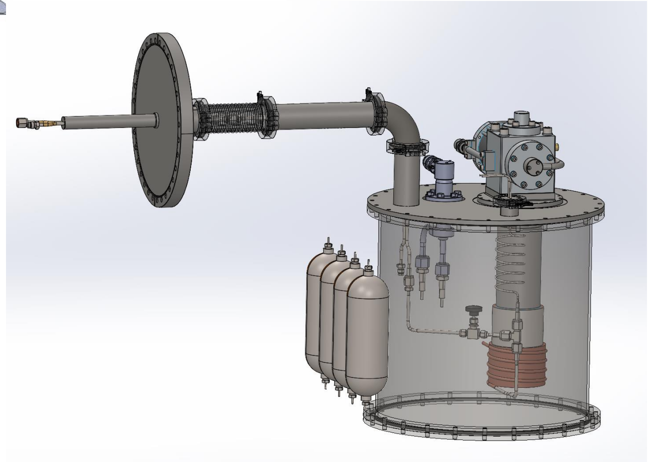


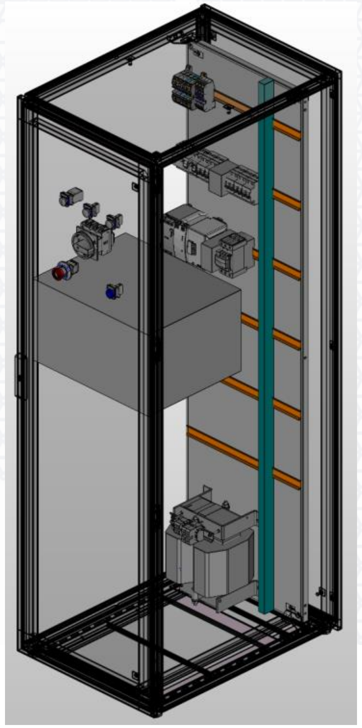
Detailed design

Subsystems detailed design







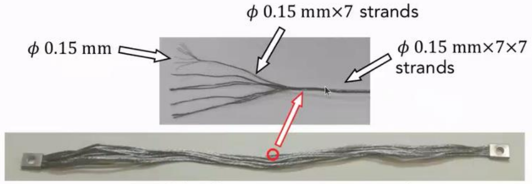


Desired platform T: a vibration specification

KAGRA heat-links

- Ultra high-purity aluminum heat-links

Purity: 99.9999%, 6N (Sumitomo Chemical Co., Ltd.)



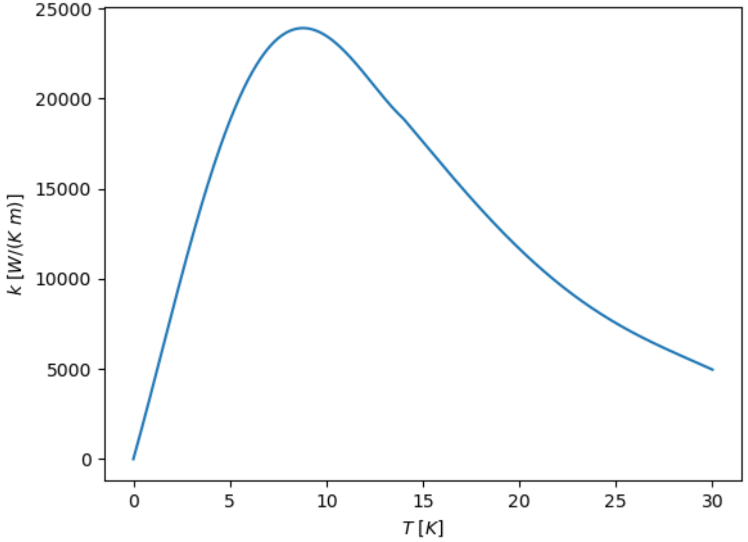
7 parallels of ϕ 0.15 mm×7×7 strands

high thermal conductivity and low spring constant(stiffness)

$$A = \frac{4}{\pi} 0.15mm^2 \cdot 7^3 \approx 10^{-5} m^2$$

$$R = \frac{\dot{Q}L}{A} = \int_{T\_interface}^{T_{platform}} k(T)dT$$

Thermal conductivity pure Al



1m Jellyfish wire at 1W

$$R = 10^5 \frac{W}{m} \cdot [2.5 \quad 1.5 \quad 1 \quad 0.5 \quad 0.2 \quad 0.1]$$