

HFML-FELIX || RESEARCH



Sustainability @ *High-Field Magnets & Free-Electron Lasers*

Radboud Universiteit



TU Delft



Universiteit
Leiden

UNIVERSITY
OF TWENTE.



rijksuniversiteit
 groningen



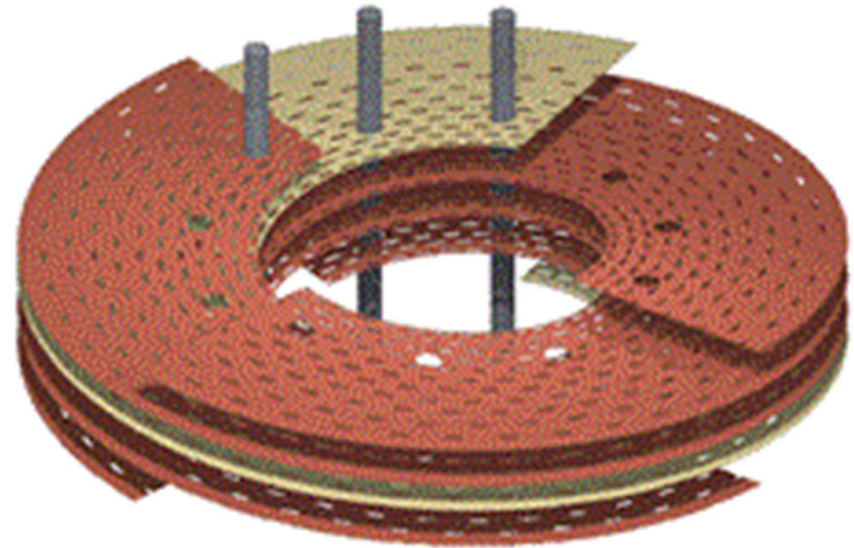
UNIVERSITY
OF AMSTERDAM



Maastricht
University

Introduction into resistive magnets

- Simplest coil: wire wound
- But: resistive conductor $\rightarrow$ heat dissipation $\rightarrow$ cooling needed!
- Solution: 1930s, Francis Bitter “cool from inside”
 $\rightarrow$ Bitter magnets
 - Made from disks
 - Stacked together
 - Insulator to form helix
 - Many cooling holes
water flow axial direction

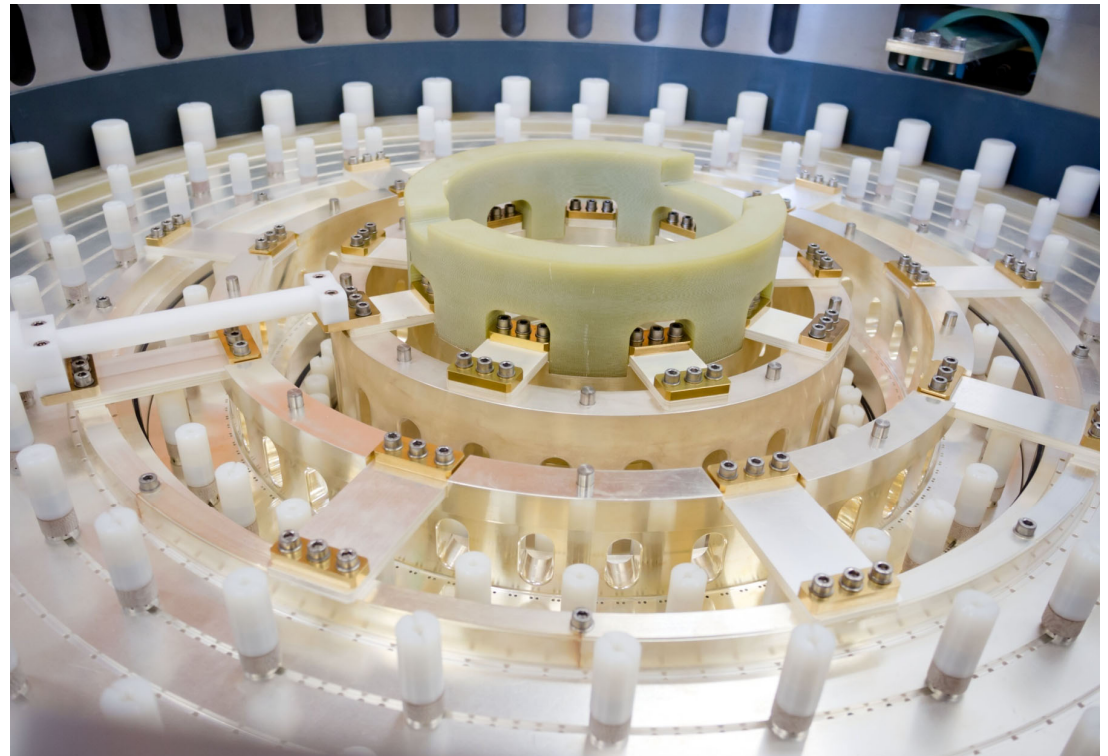
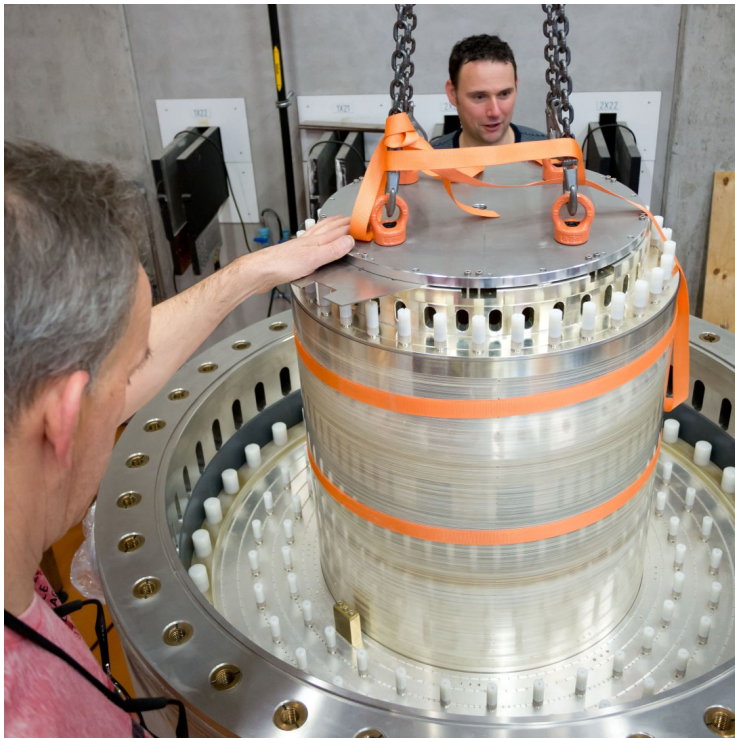
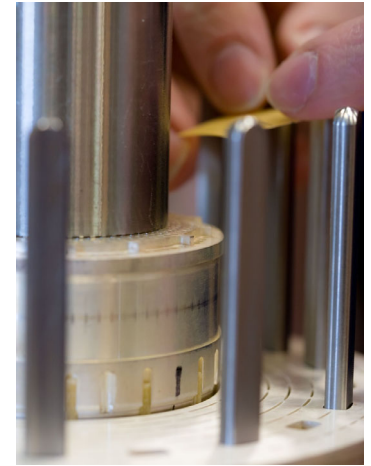
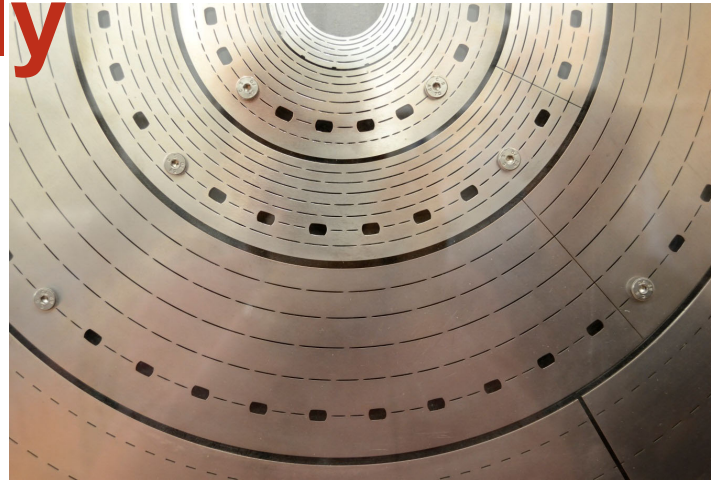


Resistive magnets available

- Current suite of magnets
 - 600 mm housing
 - 2x 33 T in 32 mm bore
 - 1x 30 T in 50 mm bore
 - 1000 mm housing
 - 1x 35 T in 32 mm bore
 - 1x 38 T in 32 mm bore
- Larger housing allows bigger coils, more field, but needs more power



Magnet assembly



Highest DC field

- Outer coil
 - Power use 2.5 MW
 - Field contribution 2.5 T
- Replace by super-conducting coil
 - “power use” ~ 100s kW
 - Field contribution 12 T
 - cryogenics
 - current injector (RT/4K)
 - redesign resistive magnet
 - ...

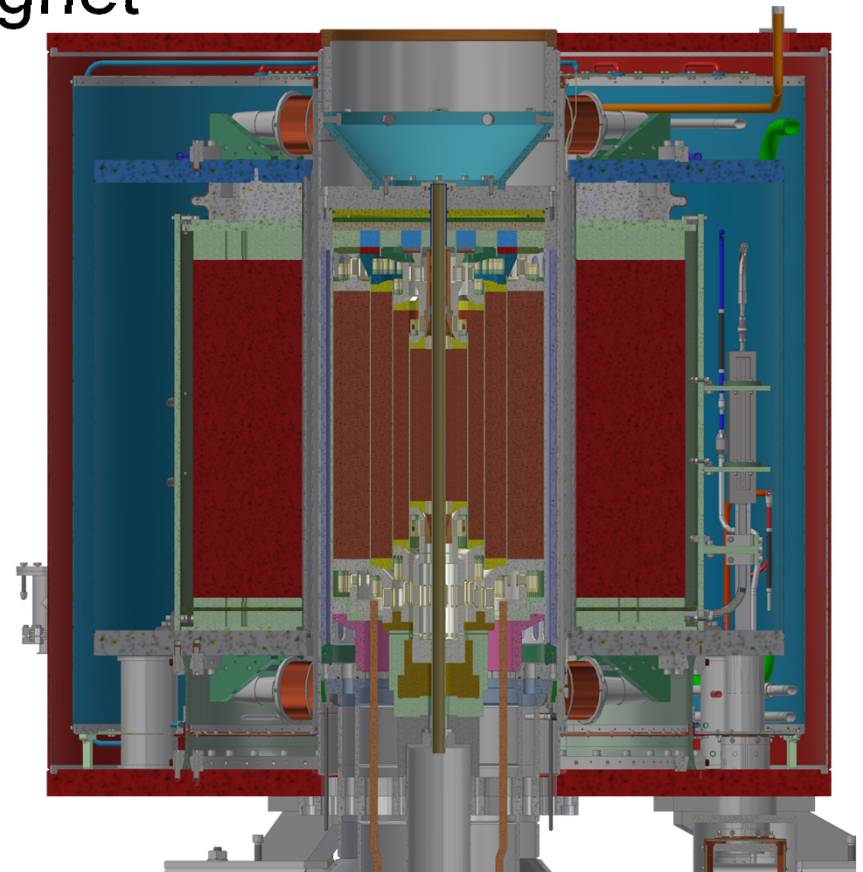
“If you can do what you want to do,
without using superconductors, then
do so without superconductors.”

first law of Den Ouden

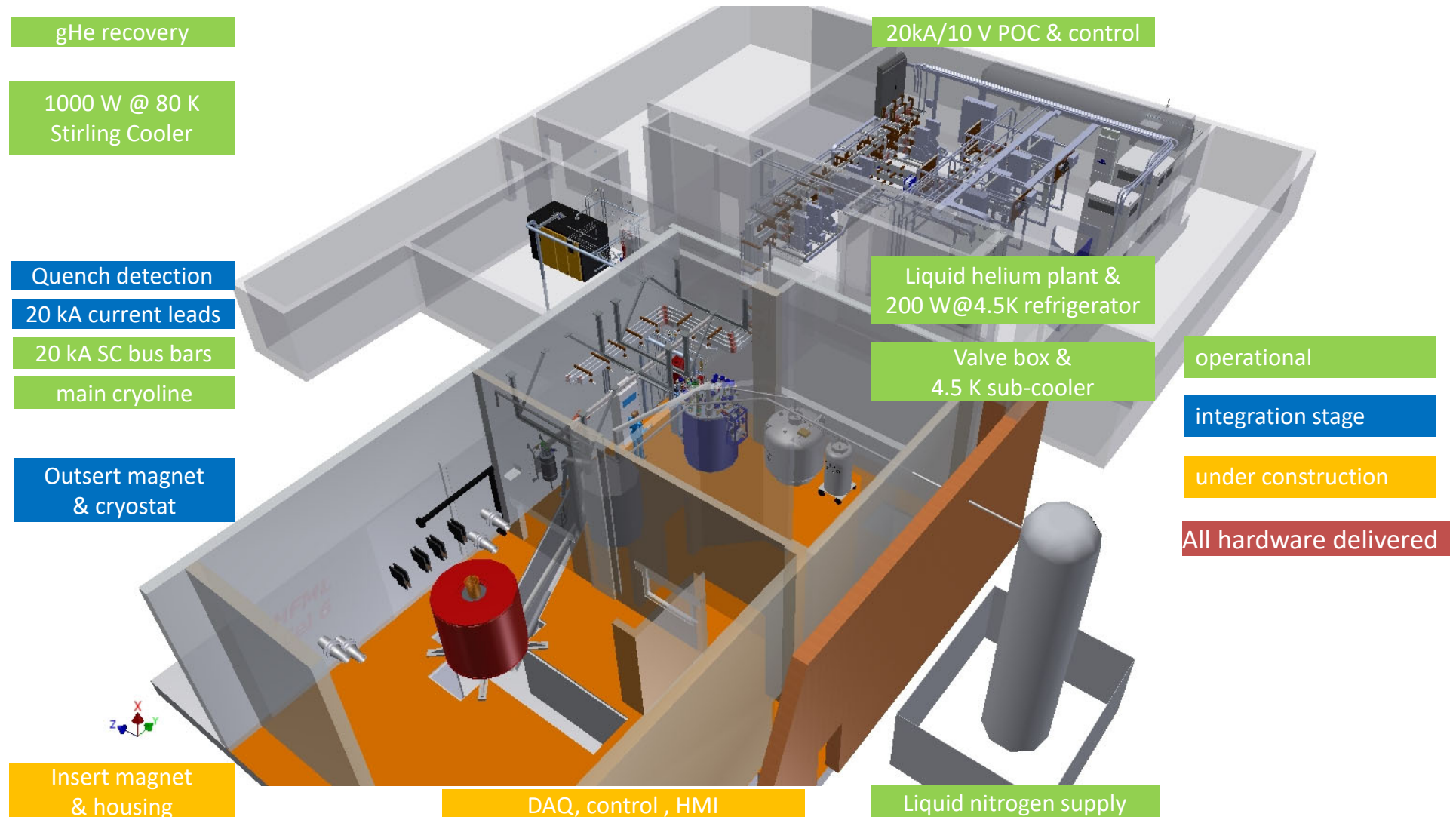


The 45 T Hybrid Magnet

- Make highest possible DC field available @ HFML
- User field of 45 T in 32 mm room temperature bore
- Superconducting outsert magnet
 - 12.3 T, 620 mm
- Resistive insert magnet
 - 32.7 T, 32 mm

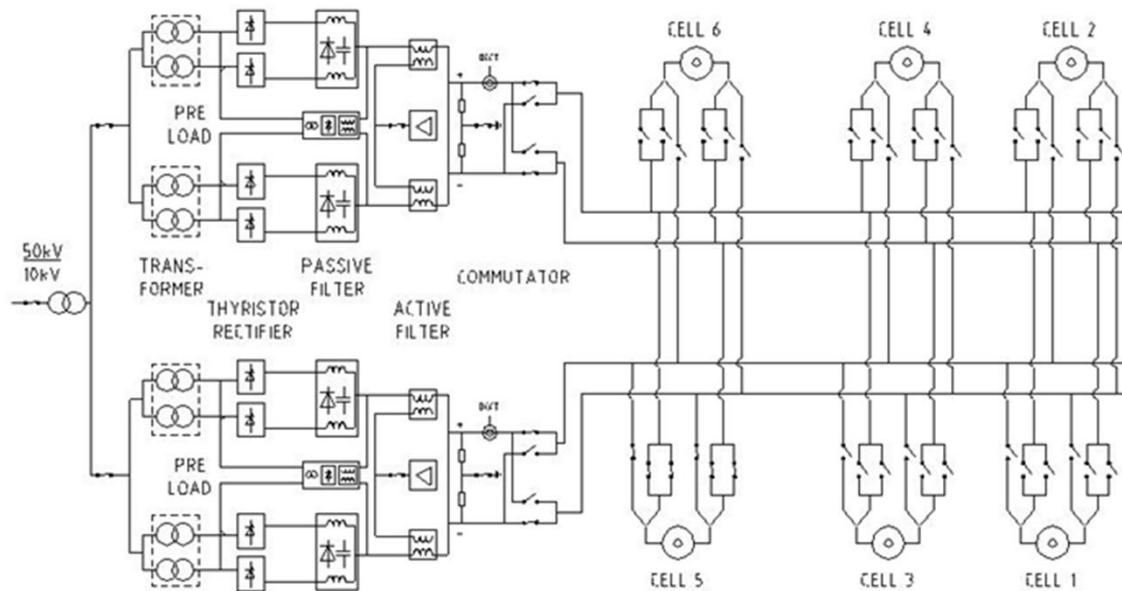


Magnet? No, it is a magnet system!



Power for the magnets

- 22 MW power converter
 - Thyristor-based rectifiers (2x)
 - Passive & active filtering
 - 40,000 A, 550 V
 - 10 ppm ripple (0.4 A top-top)

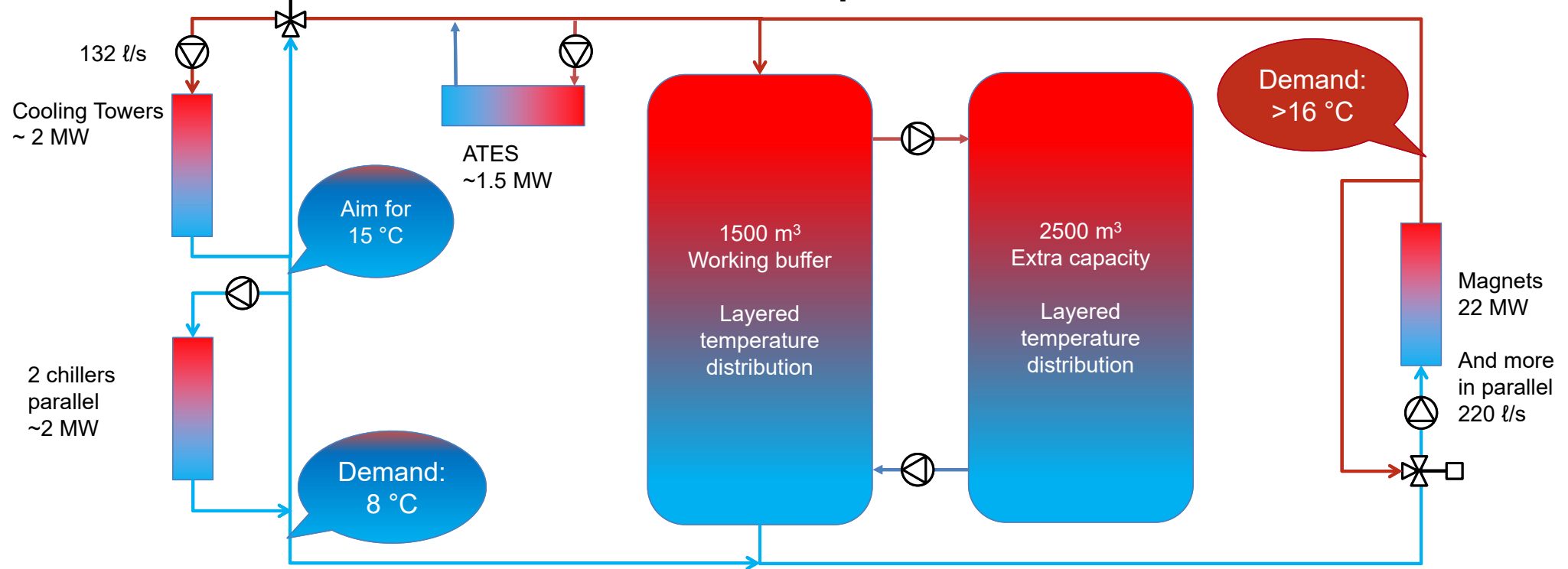


Average power ~ 7 MW
Typical energy consumption:

- Per hour 4.5 MWh
- Annually 5-12 GWh

Cooling the magnets

- No direct cooling, we use large underground water tanks to store heat/cold
- 700 kW needed to run magnet cooling
- 900 kW needed to run cold plant



Heat loads & sustainability

Year	Q_{mag} [MWh]	Q_{bld} [MWh]	Q [MWh]	ATES [MWh]	ATES [%]
2016	9695	1412	11106	207	2
2017	12335	1458	13793	1235	9
2018	10634	1542	12176	1466	12
2019	9633	1526	11159	1360	12
2020	5430	1243	6673	926	14
2021	4065	1353	5418	939	17
2022	8922	1361	10283	2761	27
2023	4173	1250	5423	2761	37
2024	5008	1145	6153	2009	29
2025	3730	1238	4968	1809	19
2026		943		752	

Buildings = ~400 MWh for HFML, Nanolab

~1000 MWh for FELIX (= building + FELs)

Use of Aquifer Thermal Energy Storage (ATES) increased slowly, big step in 2022: process cooling FELIX optimised.

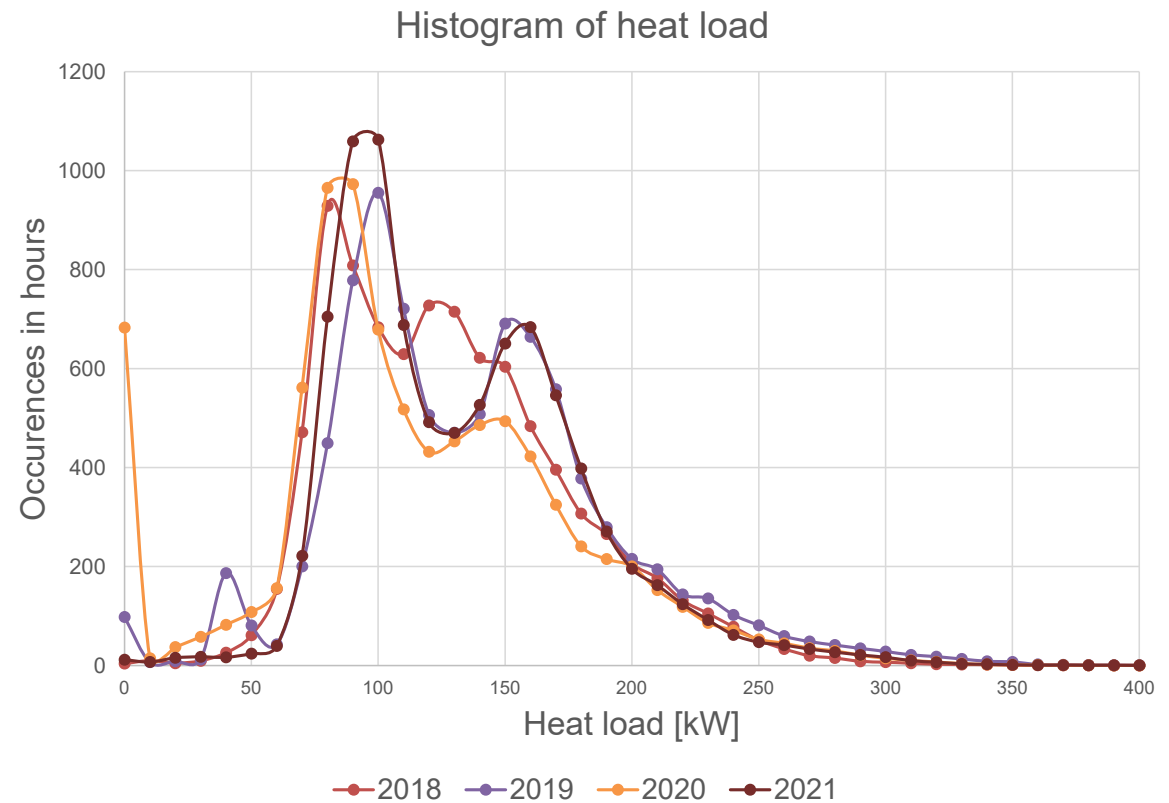
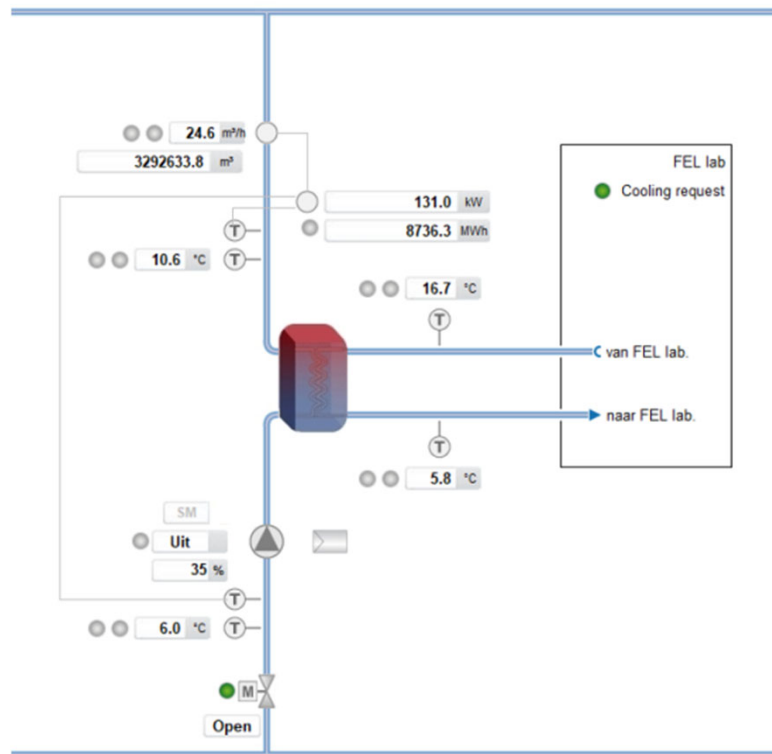
in 2023: optimisation of cooling plant (manual experiments)

Heat sources

Source	Power, Energy	Temporal profile
Magnets	Peak 22 MW Average 4 MWh/h -> 6000-8000 MWh/yr	09-14 / 14:30-22:00 1500-2000 h/yr
Power Converter	50-300 kW	As magnets
FELs + building FELIX	100-250 kW ~1000 MWh/yr	24/7
HFML building	20-100 kW ~200-350 MWh/yr	24/7
Liquefier	100 kW	24/(3 out of 7)
Lab equipment	10-30 kW	Intermittently 24/7

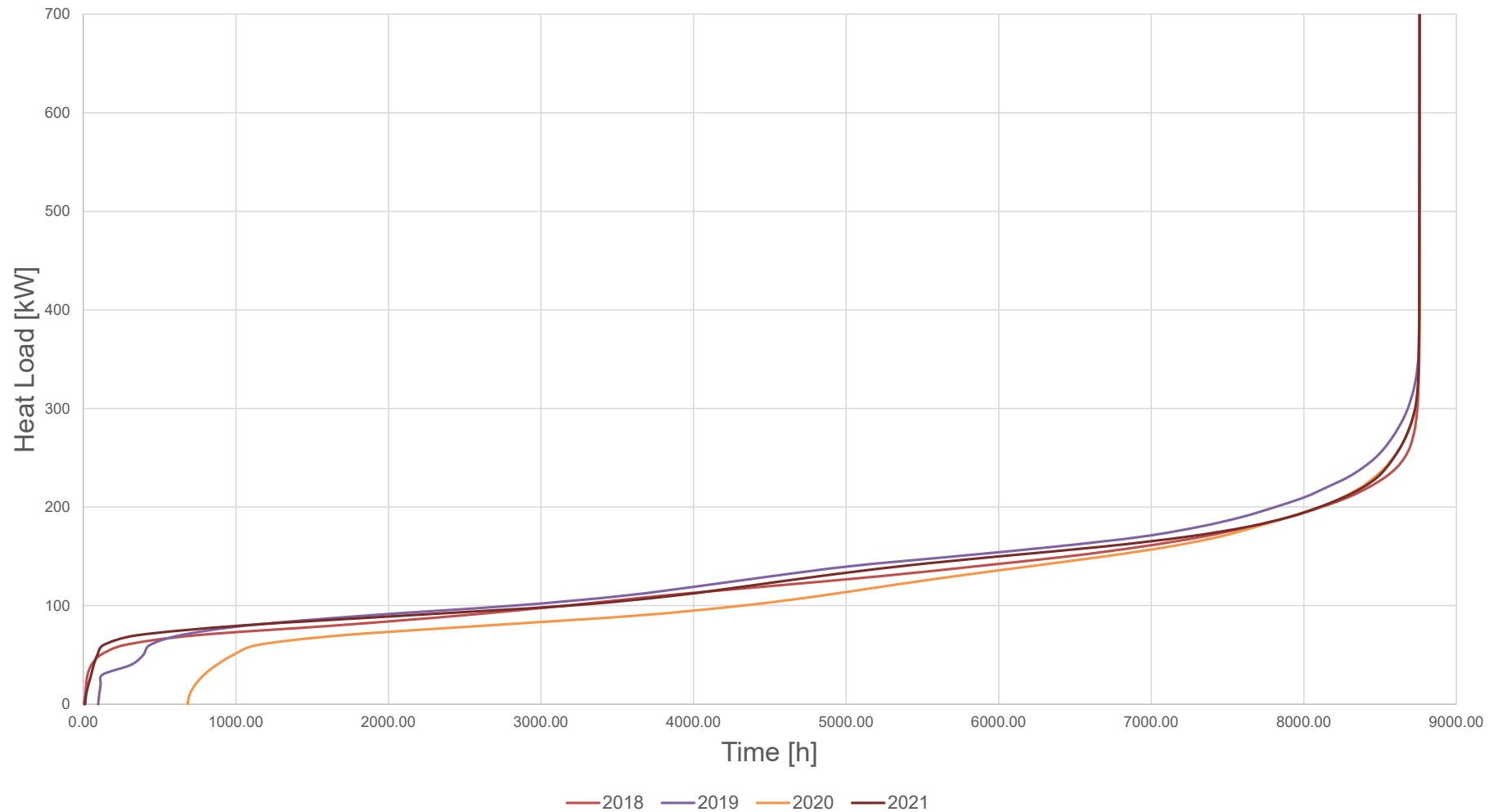
Optimise cooling processes

- Example of a typical situation
- Heat load during design phase overestimated



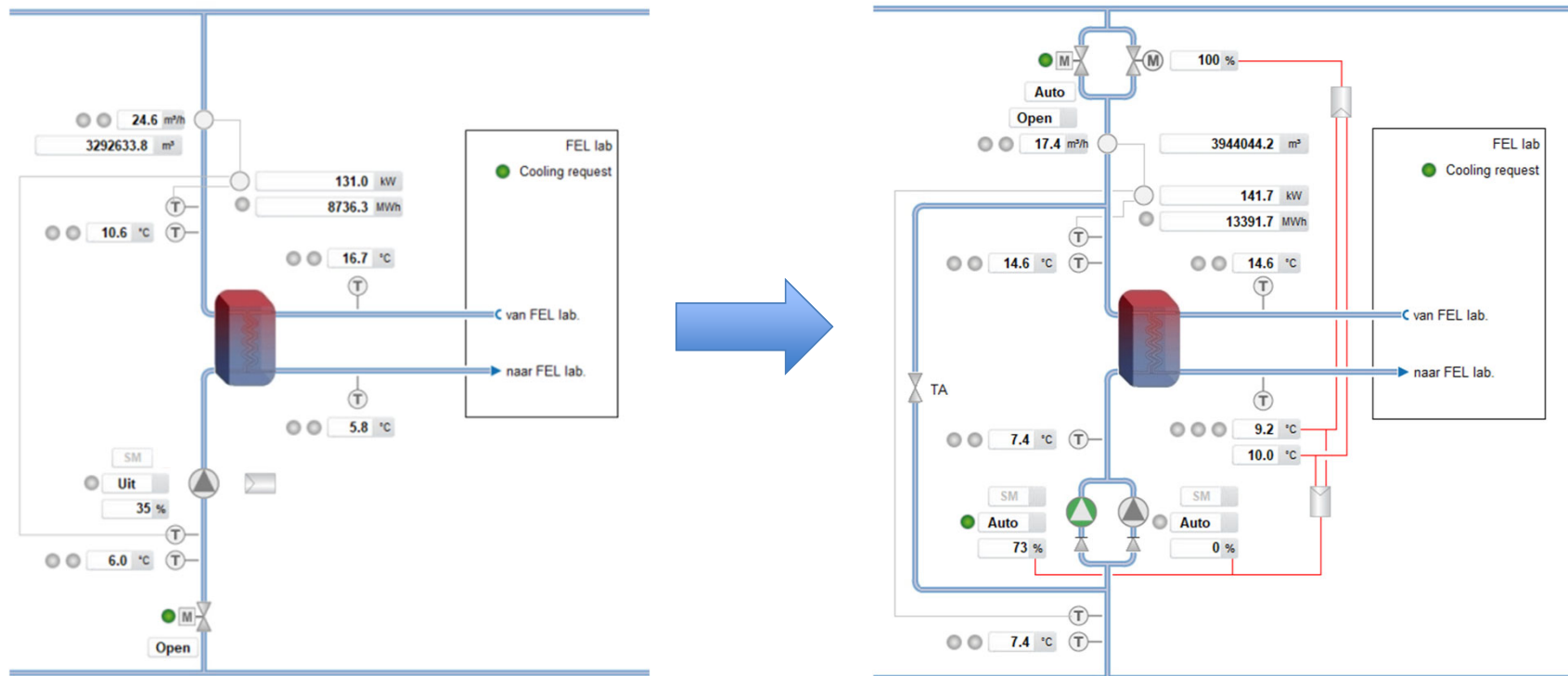
Translate to yearly impact

Year-Use curve of heat load FELIX



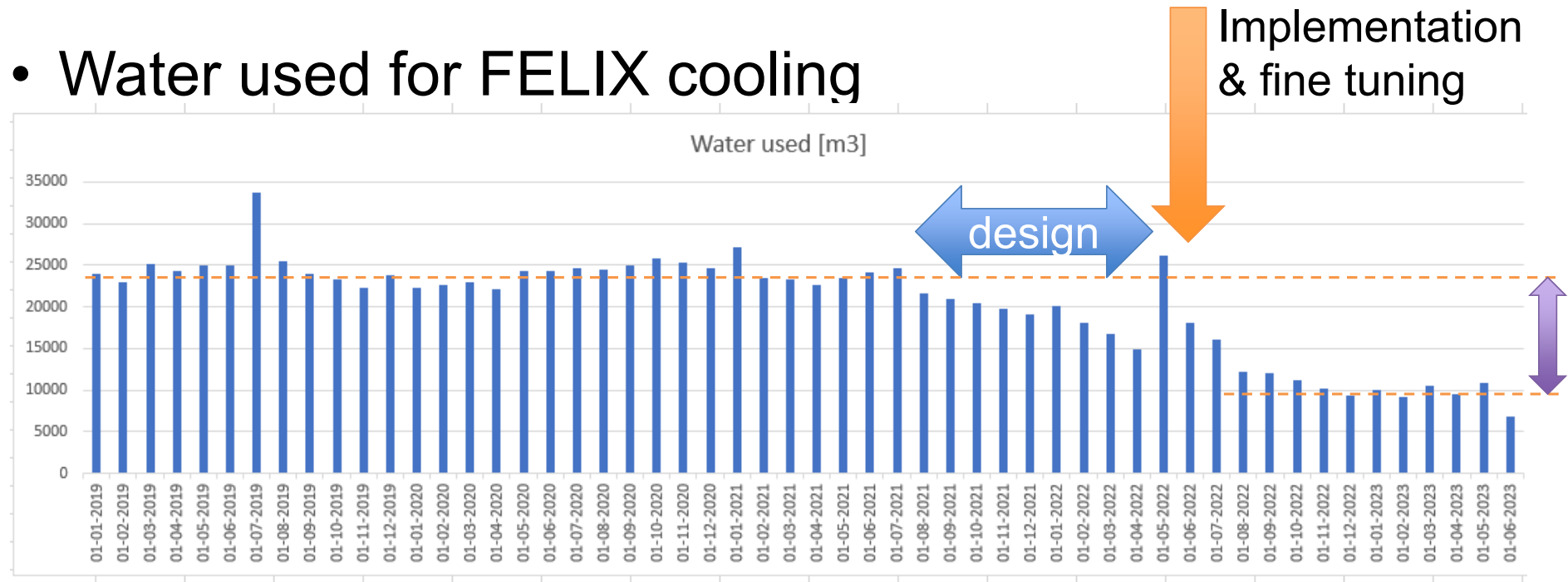
New situation

- Replace pump, increase flow control range
 - Allows lower flow, increases return temperature
 - Reduce water needed for cooling
- Increased return temp matches demand from ATEs



New situation

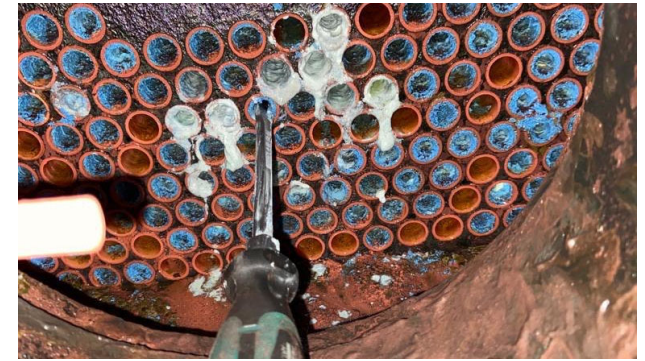
- Water used for FELIX cooling



- Reduction $\sim 24.000 \text{ m}^3/\text{month}$ to $\sim 10.000 \text{ m}^3/\text{month}$
- Cold plant runs less frequent $\sim 300 \text{ MWh/yr}$ saved
 - Less frequent, but higher ΔT though (but ATES compatible)

Other activities

- Optimisation
 - A few more processes to go
 - Heat exchanger performance & cleaning
- Equipment replacement
 - always with an eye on energy efficiency
- Grid congestion
 - On-going process with grid operator for 19 MW flex power contract



Radboud University

