



# Cryogenics at the European Spallation Source

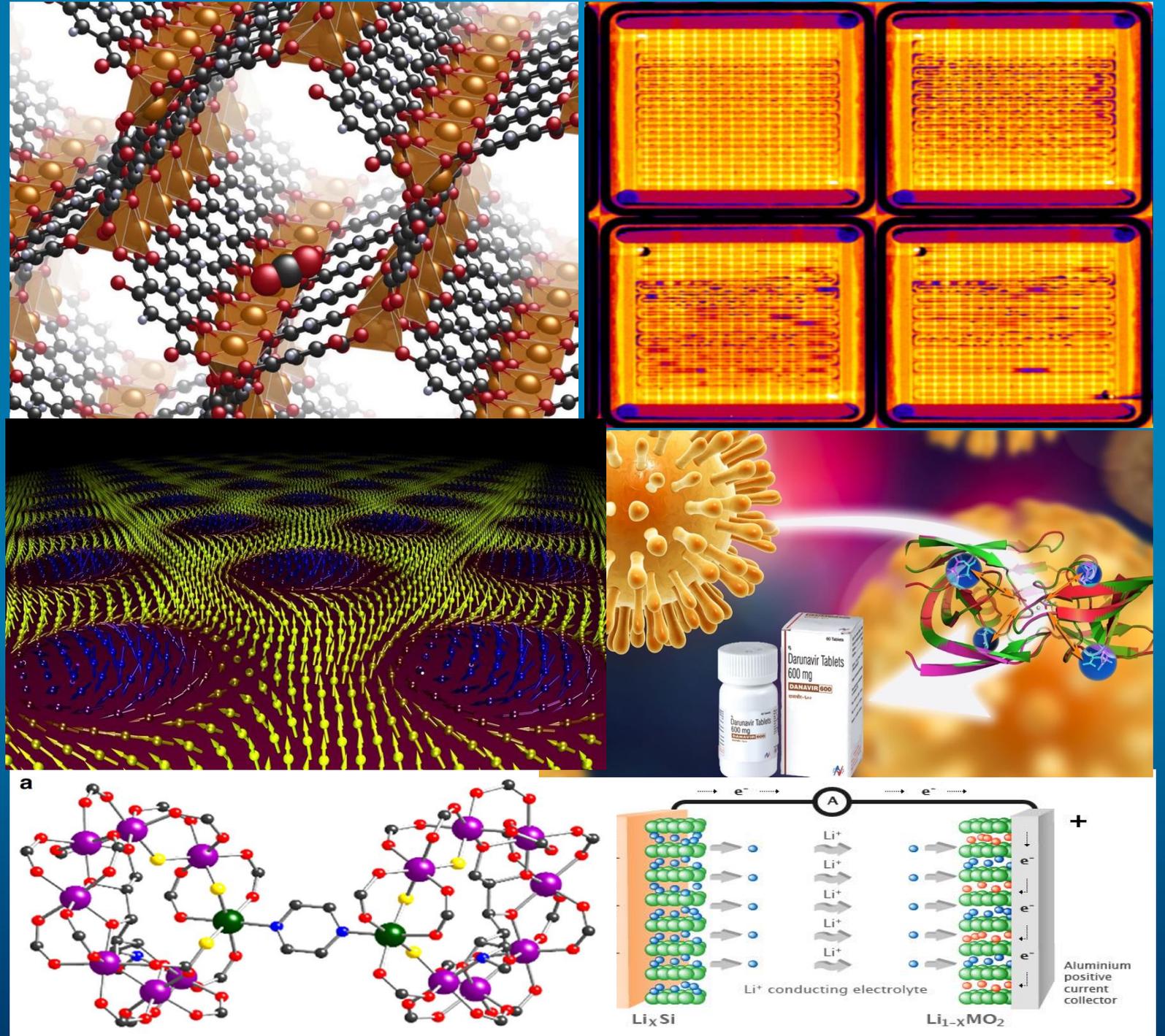
On the way to steady state operations

PRESENTED BY PHILIPP ARNOLD

2025-11-03

# Neutron Science for Society

- Neutrons let scientists see where atoms are and how they behave – revealing information on the atomic level.
- Enables development of better batteries, greener plastics, quantum materials and stronger engineering materials.
- Helps life scientists develop new vaccines and more effective medicines/treatments.



# 15 instruments under construction

Each instrument designed to be world-leading at 2MW



Life sciences



Soft condensed matter



Chemistry of materials



Energy research



Magnetism & superconductivity



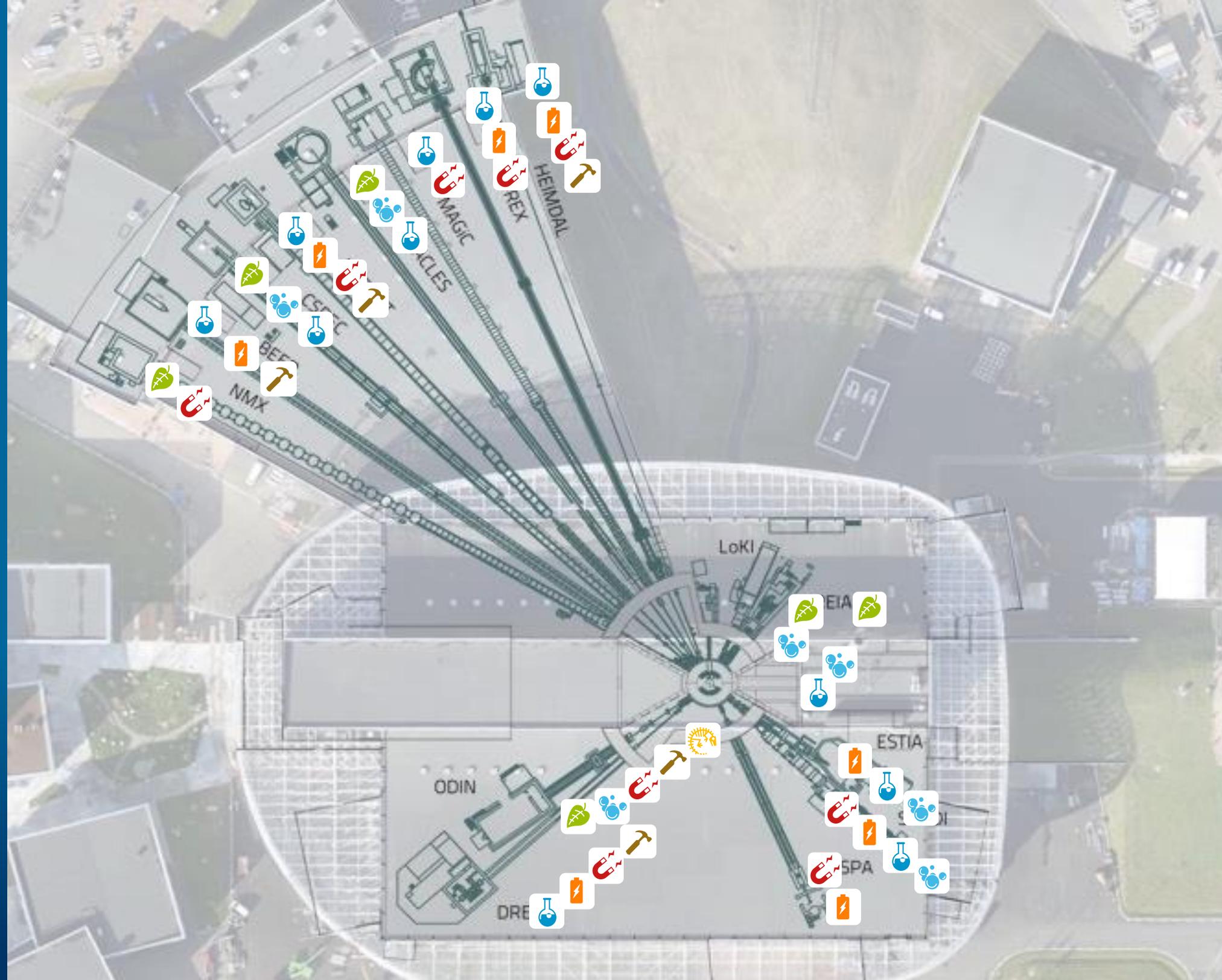
Engineering & Geo-sciences



Archeology & Heritage conservation



Fundamental & particle physics



# 13 European countries joining forces and sharing a common ambition

---

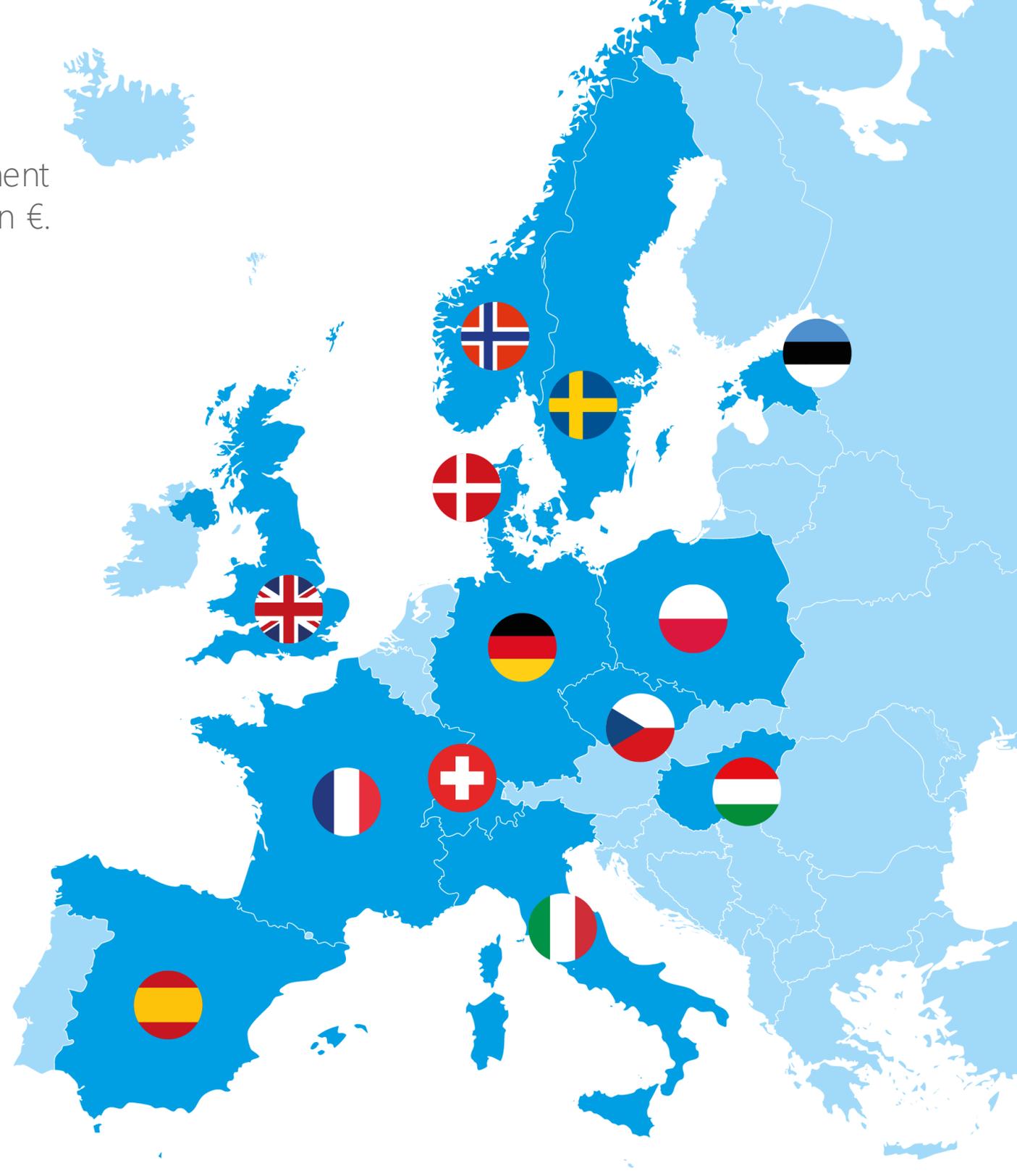
Host States:

Sweden, Denmark.

Member States:

Czech Republic, Denmark,  
Estonia, France, Germany,  
Hungary, Italy, Norway, Poland,  
Spain, Sweden, Switzerland,  
United Kingdom

A 3 Billion € project,  
with an estimated annual  
operations and development  
cost of close to 200 million €.



# Cryogenics for neutron science

## Neutrons and Cryo go well together



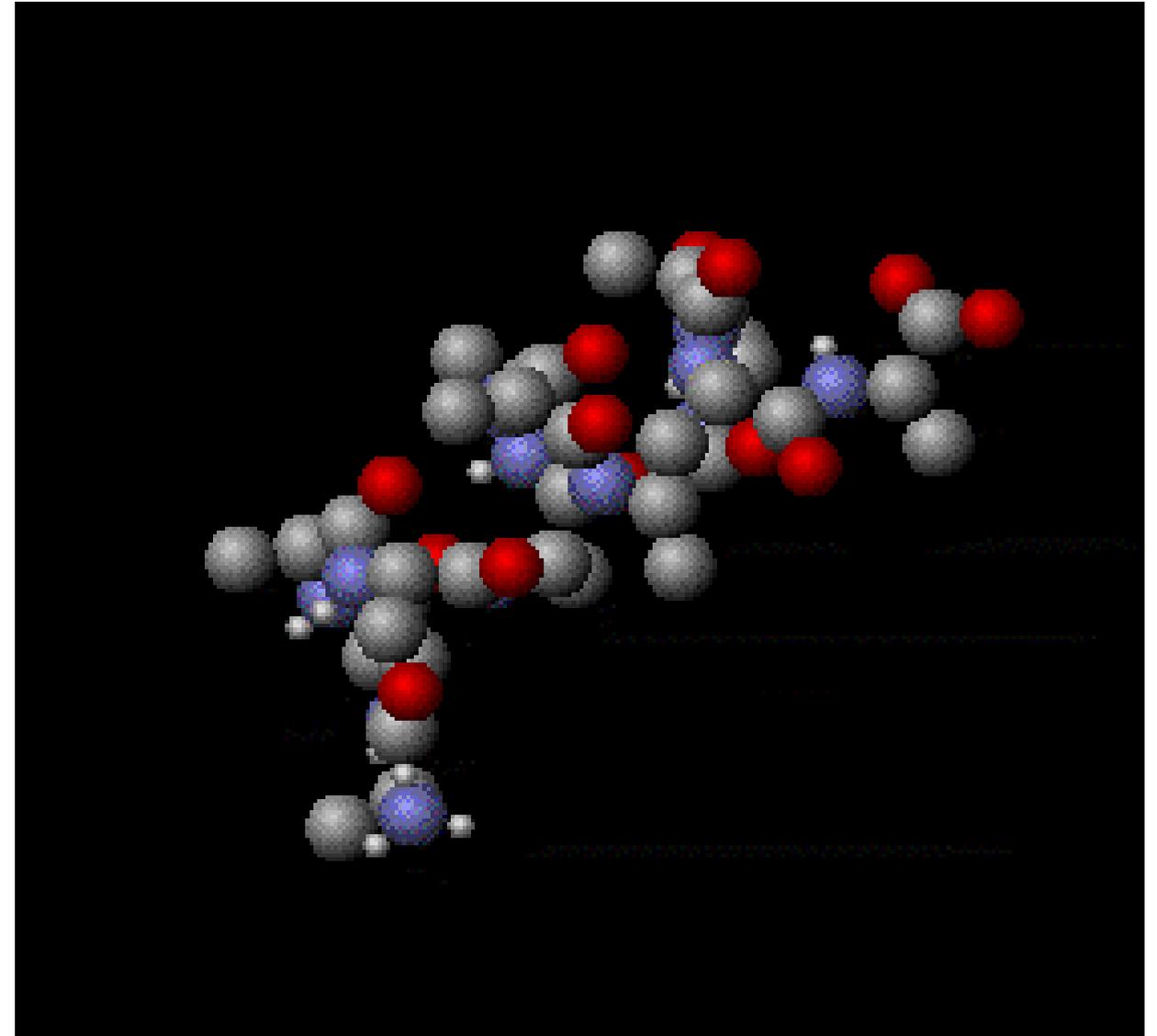
Muting the dominant particle vibrations

Tickle out the quantum behaviour

Creation of high magnetic fields

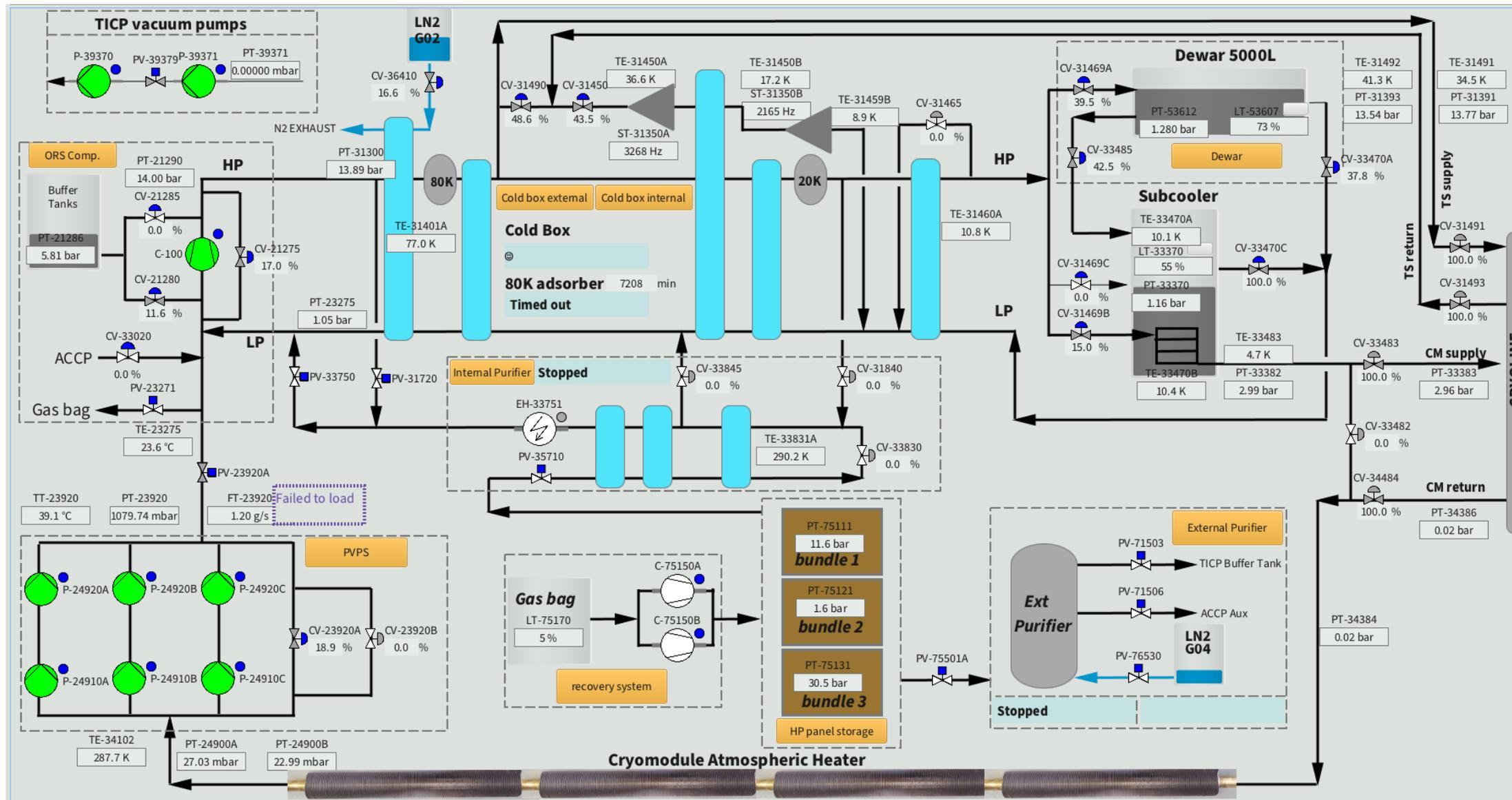
Creation of even lower temperatures

Liquid helium from TICP one of the main utilities for Physics and Materials Support Team in charge of sample environments



# The smallest cryoplant at ESS

## Test and Instruments Cryoplant (TICP) supplying TS2 and NSS



Liquefaction ~ 140 l/h w/ LN2, based on Helial ML

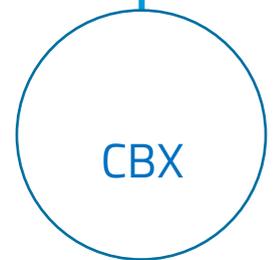
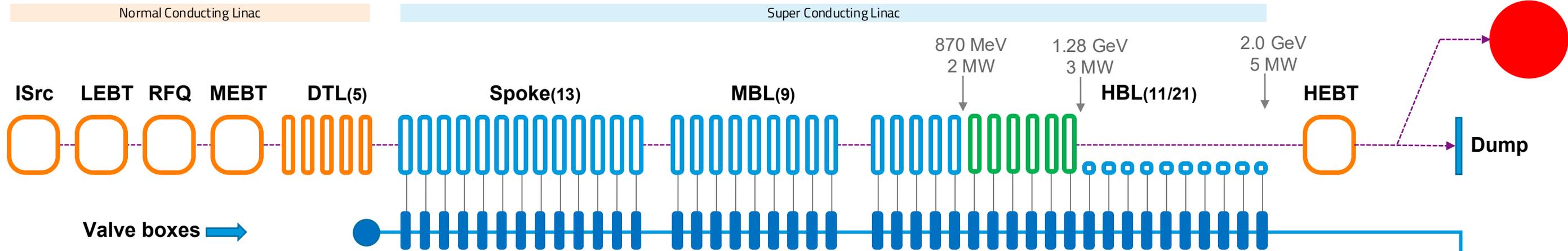
Refrigeration 4.1 g/s "const level liq" for 2K and ~400W @ 40K thermal shield

Recovery system with 100 m3 gasbag, 2x 60m3/h HP compressors, ext. purifier ~3.1 g/s

LHe vessel 5500 l  
Dual semi/auto filling station  
Boil-off station for 20 mobile dewars

# Cryomodules and Distribution System

## Cryogenics for the Super Conducting Linac in a nutshell



Accelerator CryoPlant

# Accelerator Cryoplant

...and auxiliary systems



Plant design for

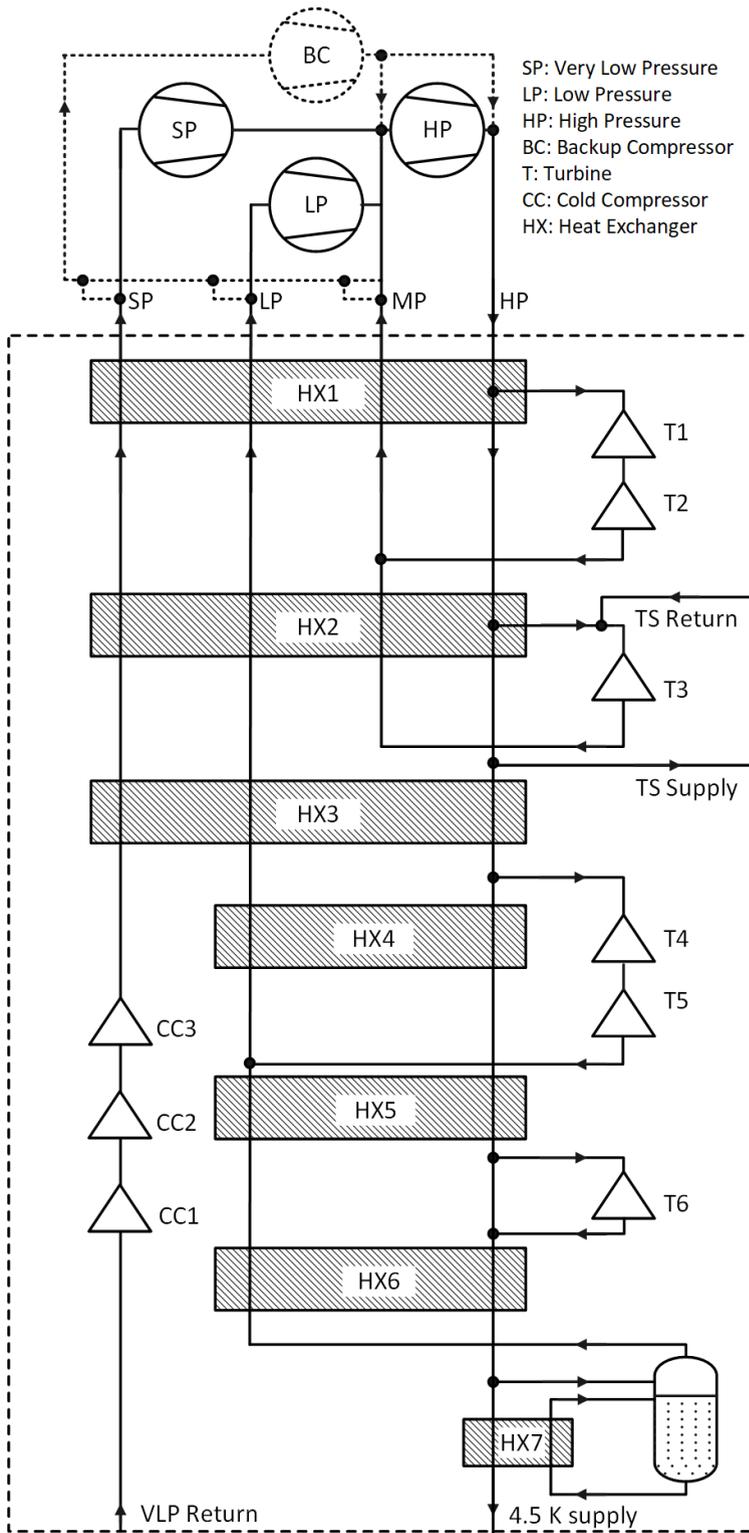
3kW @2K,  
9g/s liquefaction  
11.4 kW @40K TS

~9kW @4.5K\_eq



Currently optimised for

1.8kW iso and 0.88kW  
non-iso @ 2K  
6.8 g/s liquefaction  
8.5 kW @35K TS



# Long road towards ESS SCL cooldown

## Focus on CDS



Full ACCP-CDS-SCL  
cooldown in  
December 2024

Mid 2023  
Fixing issues and  
second Cooldown

- Few leaks (~5% of valves) ✓
- CDS-el valve mis-alignment ✓
- Endbox liquid carry-over ✓
- Report @ CryoOps Grenoble

Mid 2020  
ACCP SAT,  
ACCP testing,  
CDS installation

More issue fixing until  
SCL cooldown  
Backup compressor

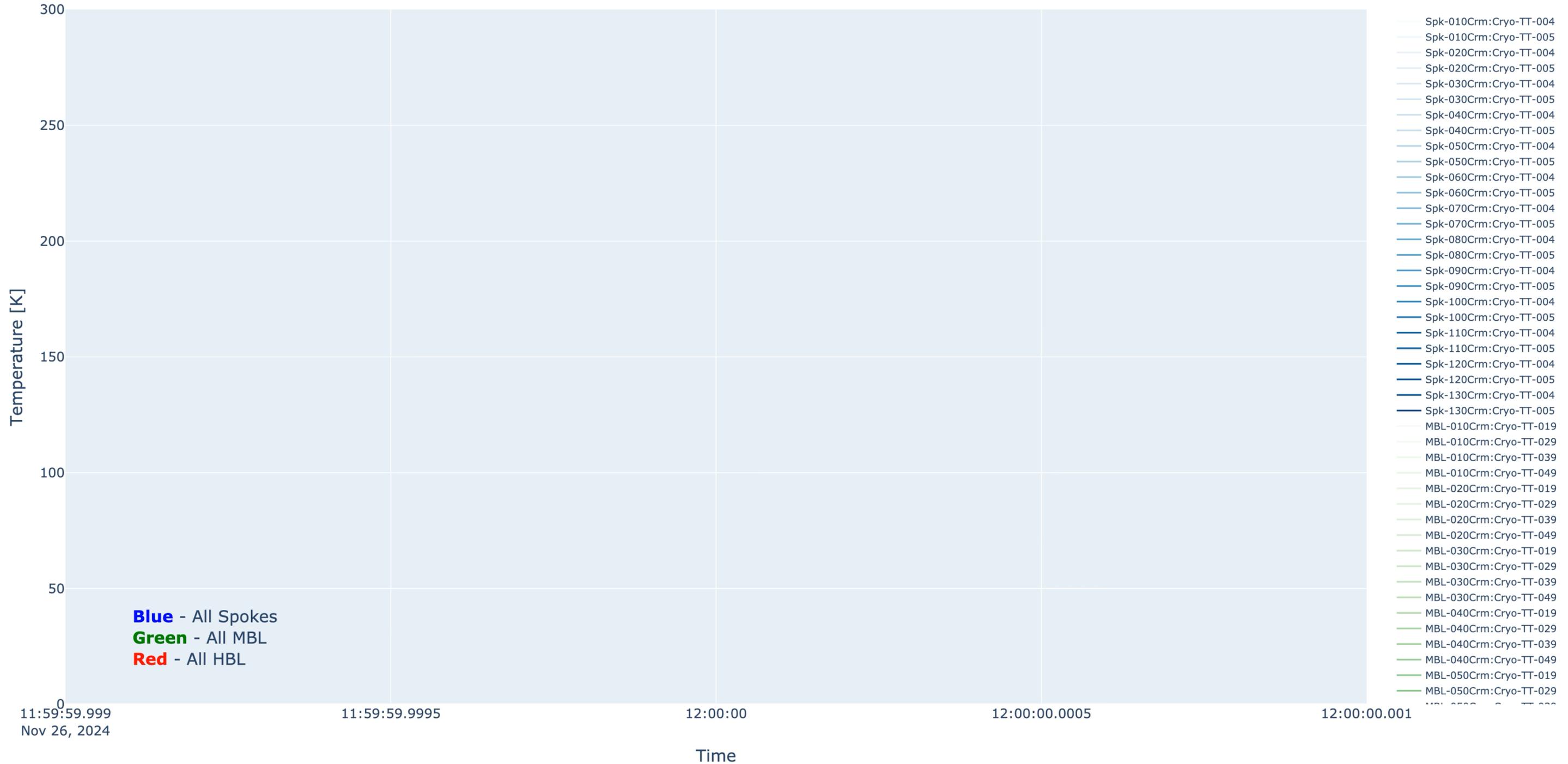
End 2022  
Pre-commissioning and  
first CDS Cooldown

- TAO on CDS-el CV04 ✓
- TAO on endbox 4K SV ✓
- Many valve leaks, ice formation... ✓, ⚠
- Report @ ECD 2023 in GSI

Substantial work  
not mentioned in  
detail here

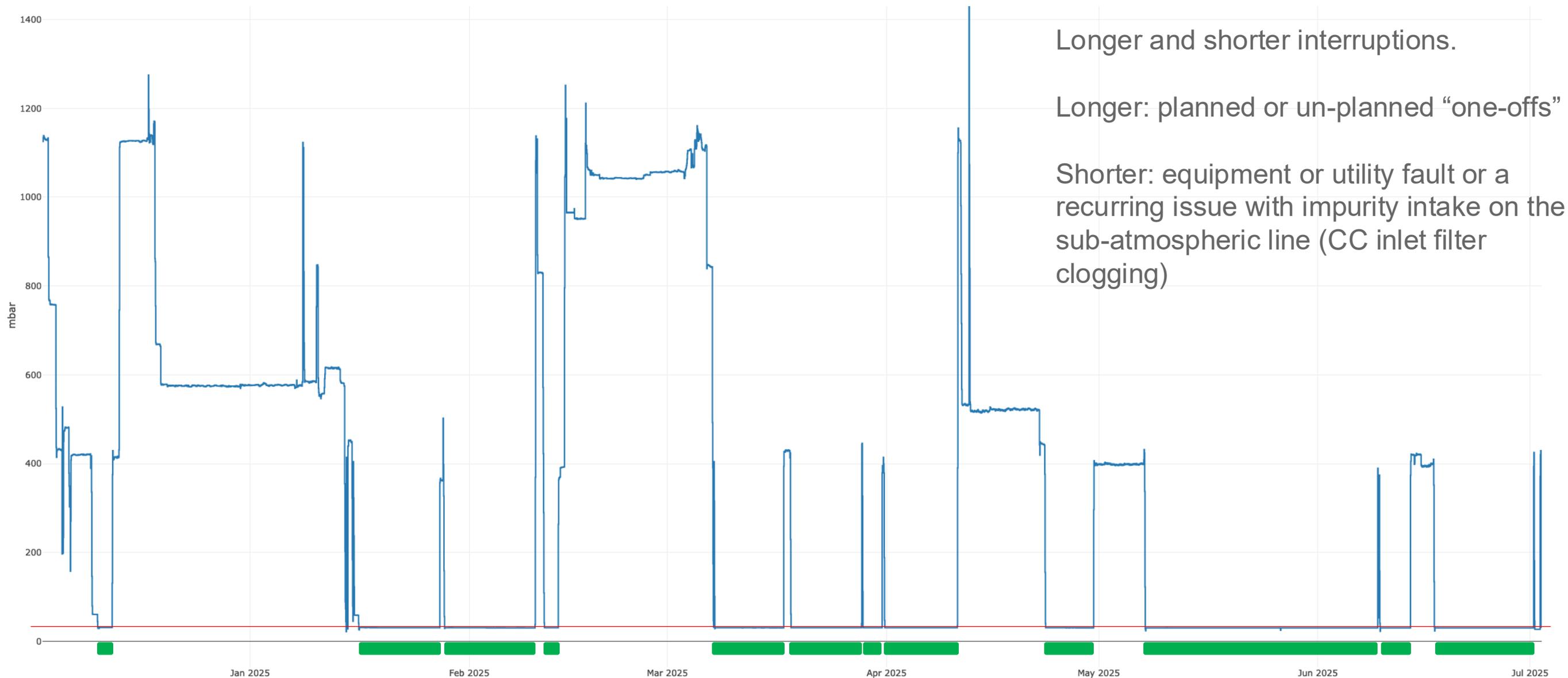
- CM testing
- CM installation
- Cryo controls
- Infrastructure
- etc.

# Temperatures Decrease Trends Over Time



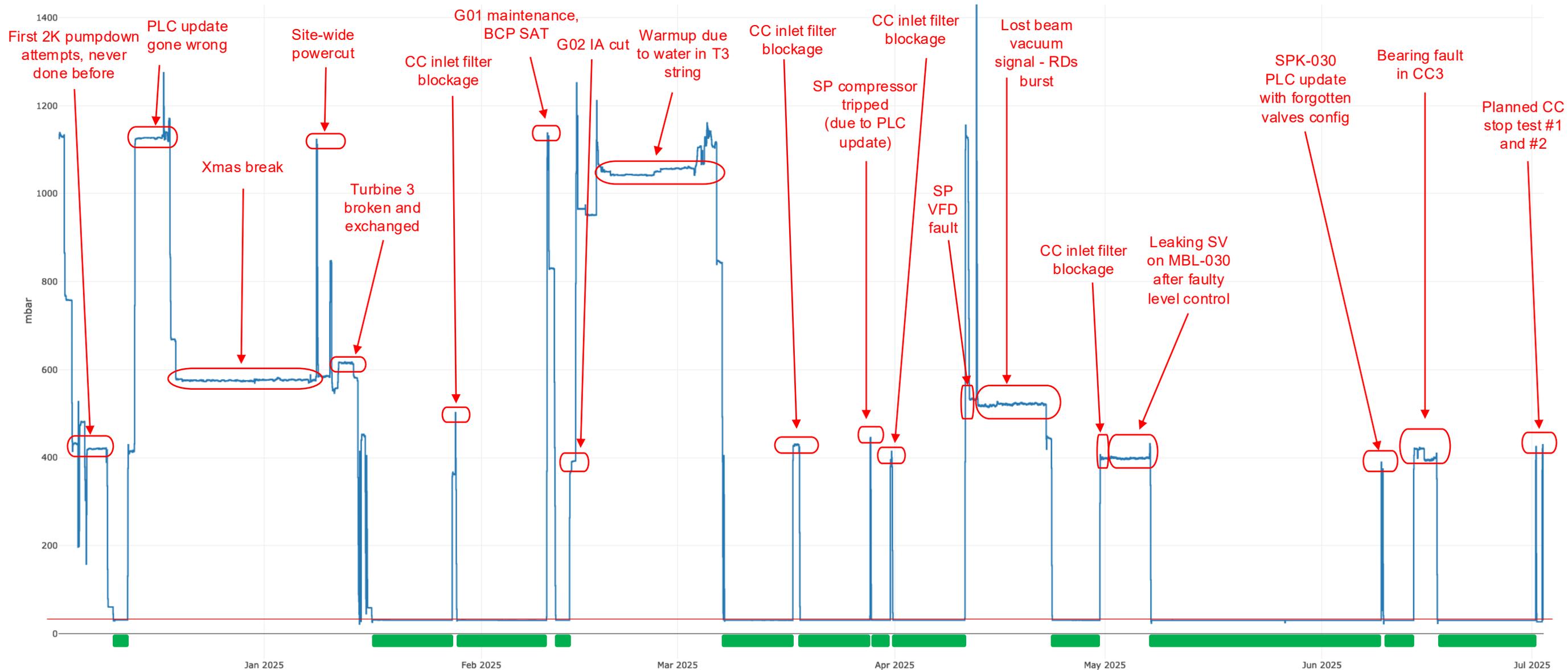
# Pressure seen in the CMs 2K circuit

can be used as indicator for stable cryo operation



# Pressure seen in the CMs 2K circuit

can be used as indicator for stable cryo operation



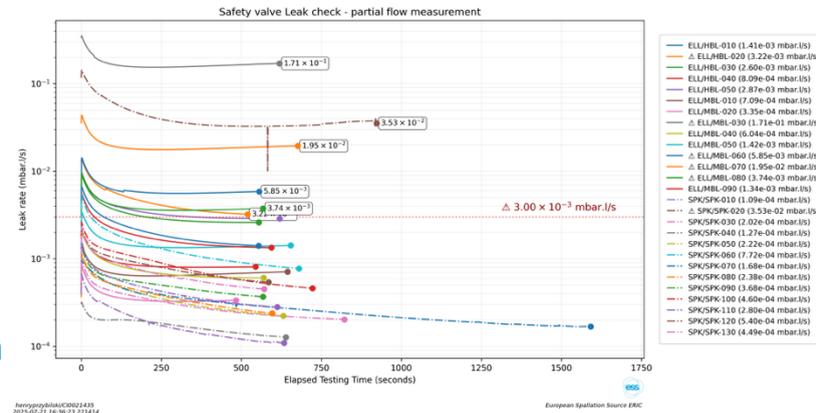
# Long summer shut-down

## To install six more HB CMs and fix things



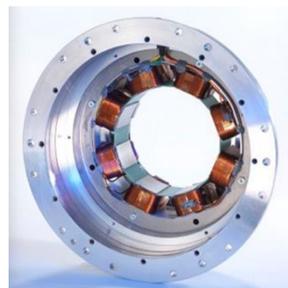
### Work on filter clogging

- Extensive leak search to identify air take-in locations
- Rectify leaks in CM and VBX SVs
- Effective helium guard for Endbox SV92
- Permanent helium guards on CV04 and CV06 in SPK CDS
- Improve pump & purge procedure to properly clean tie-in to SV relief line
- Remove CC inlet filter



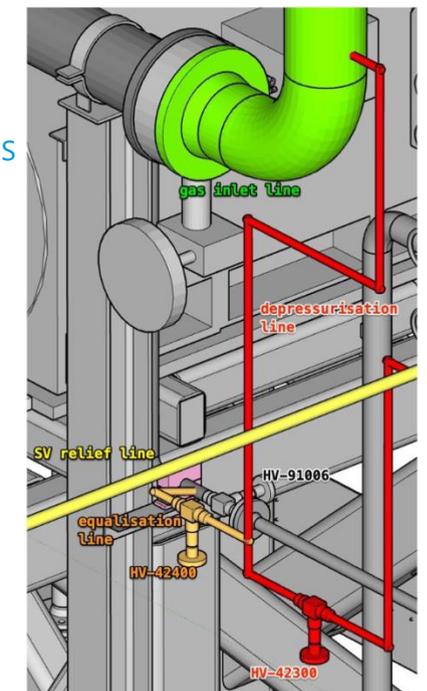
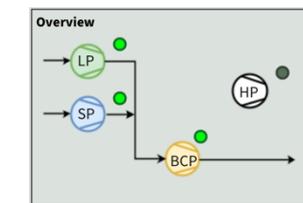
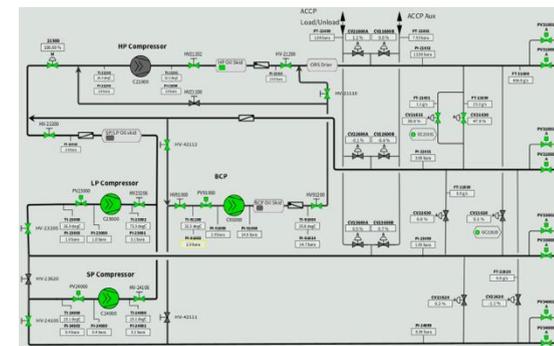
### Work on cold compressors

- Preventive maintenance – motor exchange
- Install SPM (shock pulse monitoring) for CCs
- Upgrade controls in preparation of AMB revamp



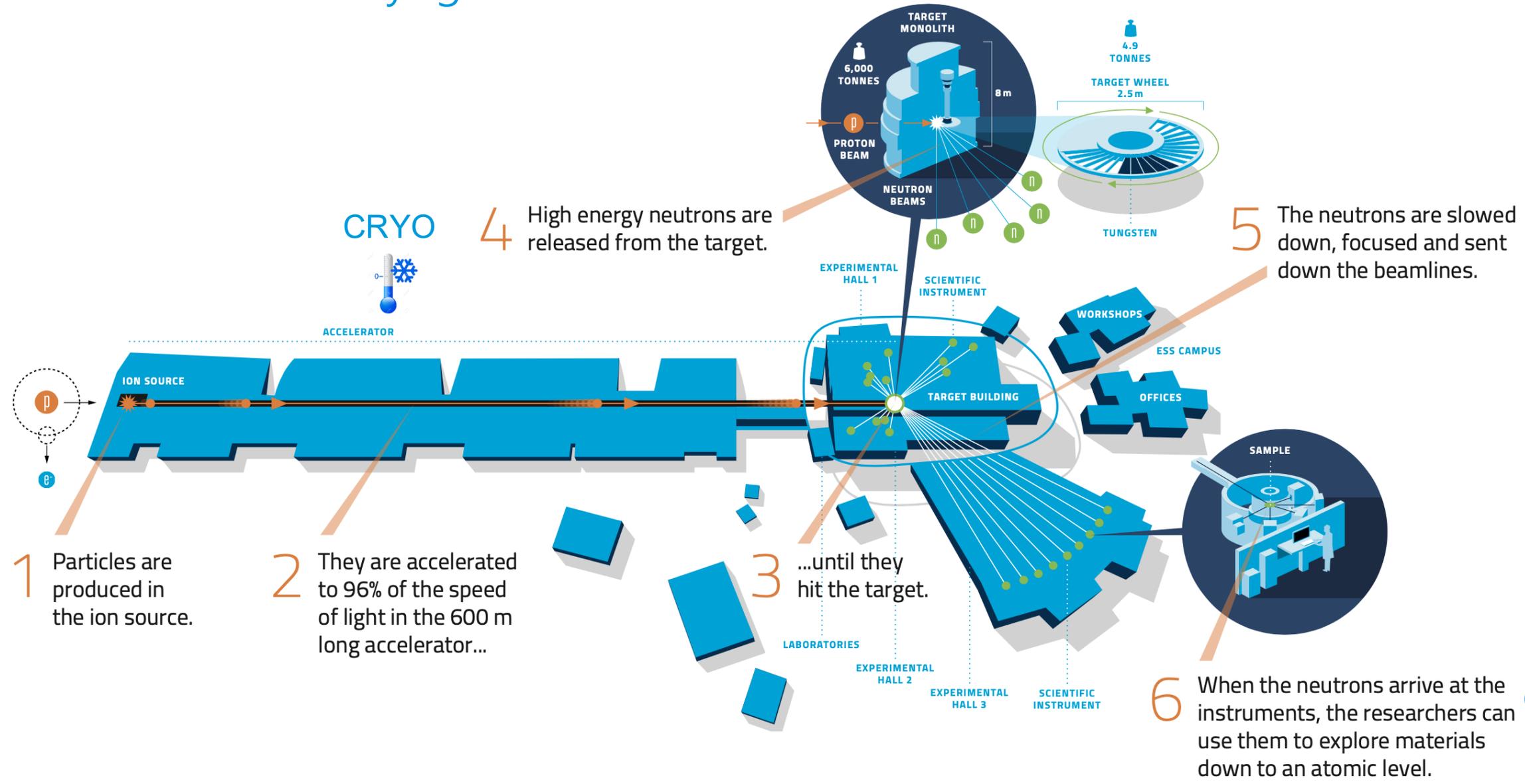
### Work on backup compressor

- Rectify helium guard leak at inlet
- Add tubing for better conditioning to run in different modes
- Test and qualify operation as LP and as SP compressor
- Prepare controls for seamless switch-over of HP and BCP
- Test, debug and verify seamless switchover



# But what about the neutrons?

## Another case for cryogenics

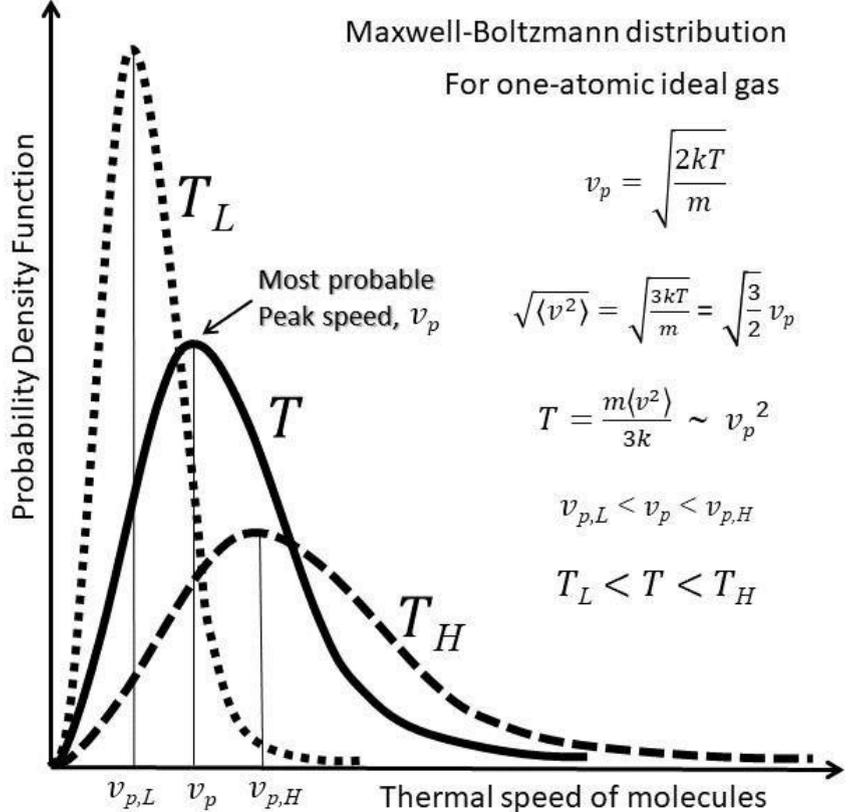


# Billiard and Boltzmann

## How we make the neutrons useful (1)



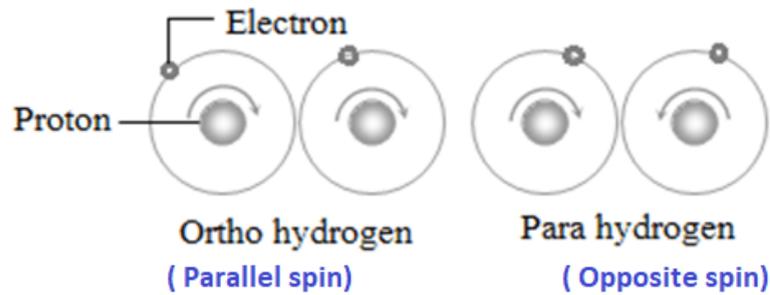
Reduce neutron energy  
of MeV (relativistic speed) to meV  
(thermal neutrons) by thermal  
moderator, water



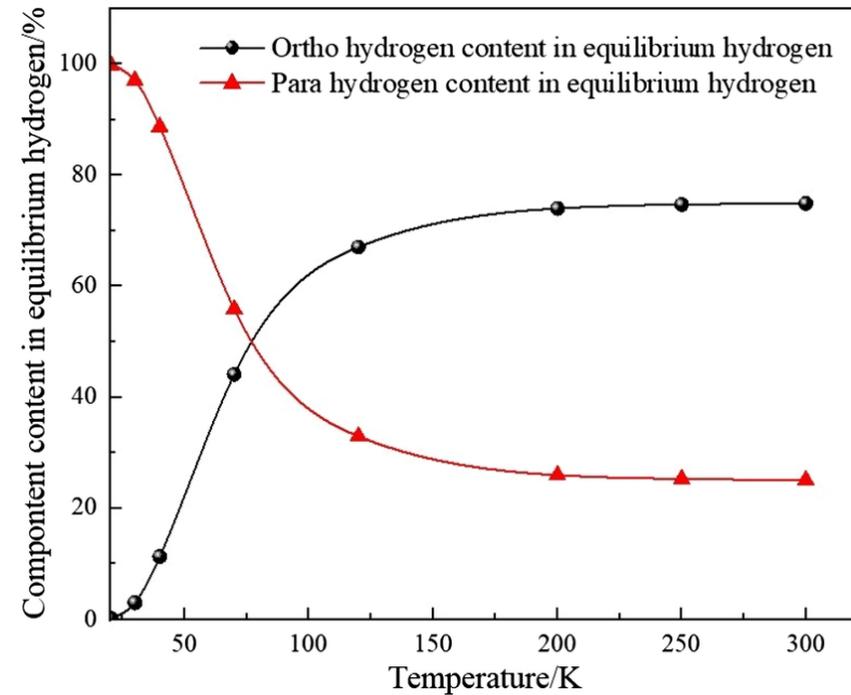
Thermodynamic energy reduction  
From thermal to cold neutrons  
The colder the moderator the slower (=colder) the  
neutrons  
Liquid hydrogen at 17-18K → equivalent neutron  
"temperature" ~50K

# Cryo for high brightness

## How we make the neutrons useful (2)

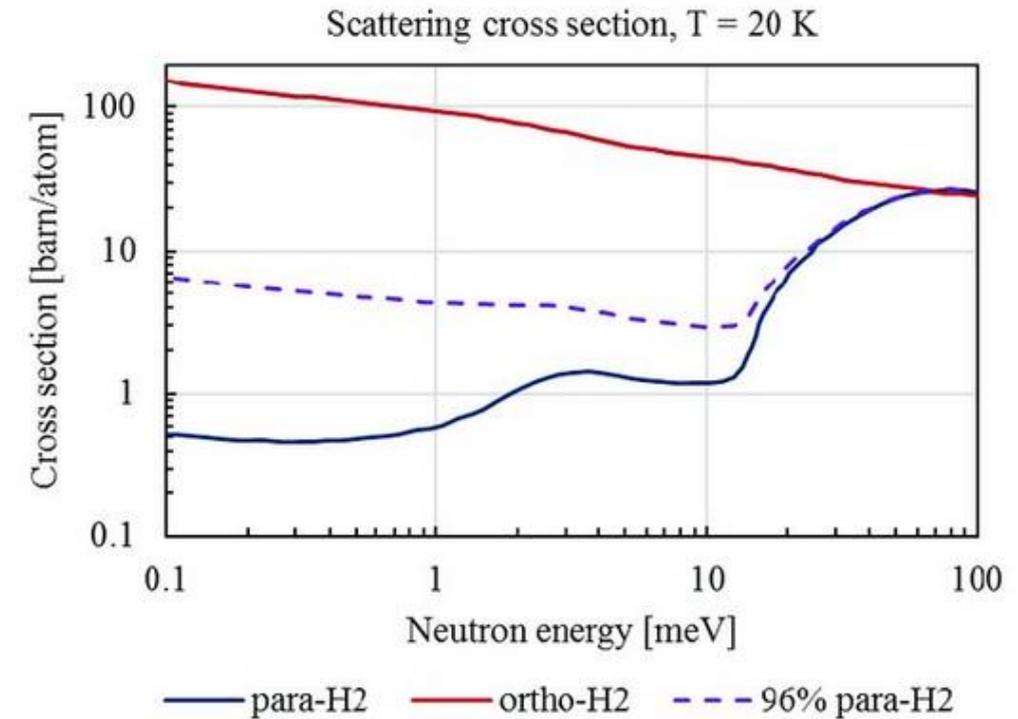


Additionally to different isotopes (Deuterium, Tritium) hydrogen has different spin isomeres



Temperature-dependent equilibrium fraction and different energy levels, catalyst required

Eisenhut, S. et al *EPJ Web of Conferences*.  
Vol. 231. EDP Sciences, 2020.



Para-H2 with very low scattering cross section for cold neutrons

→ on flat moderators neutrons can penetrate deep and still come out again

# Realisation at ESS

Many contributors



H2 jumpers in connection cell to cold flat moderators

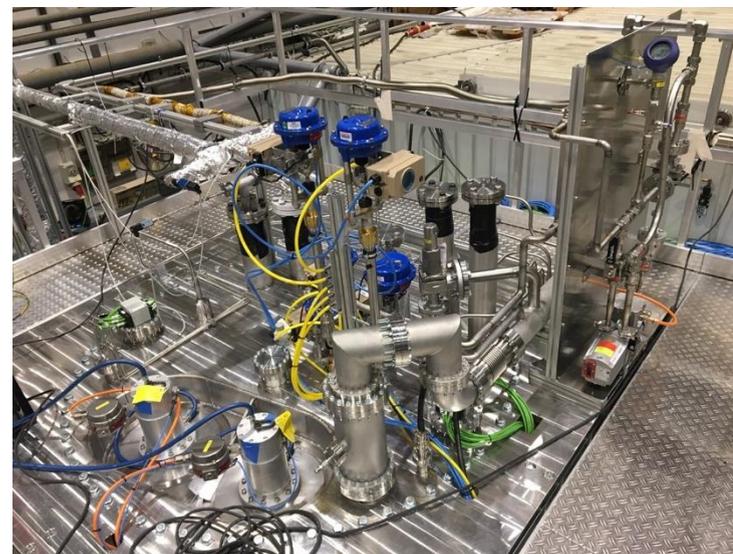
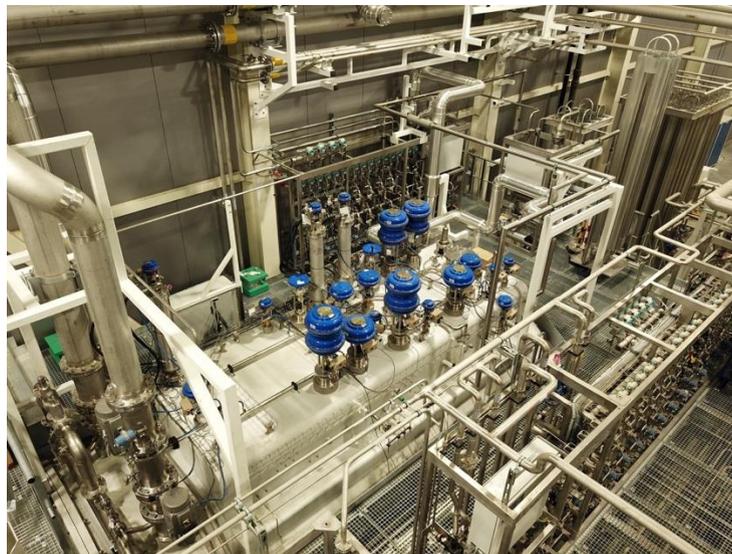


TMCP design for 30kW @15-20 K,

17 kW H2 heater



CMS design for ~1000 g/s H2 circulation



H2 distr Vbx

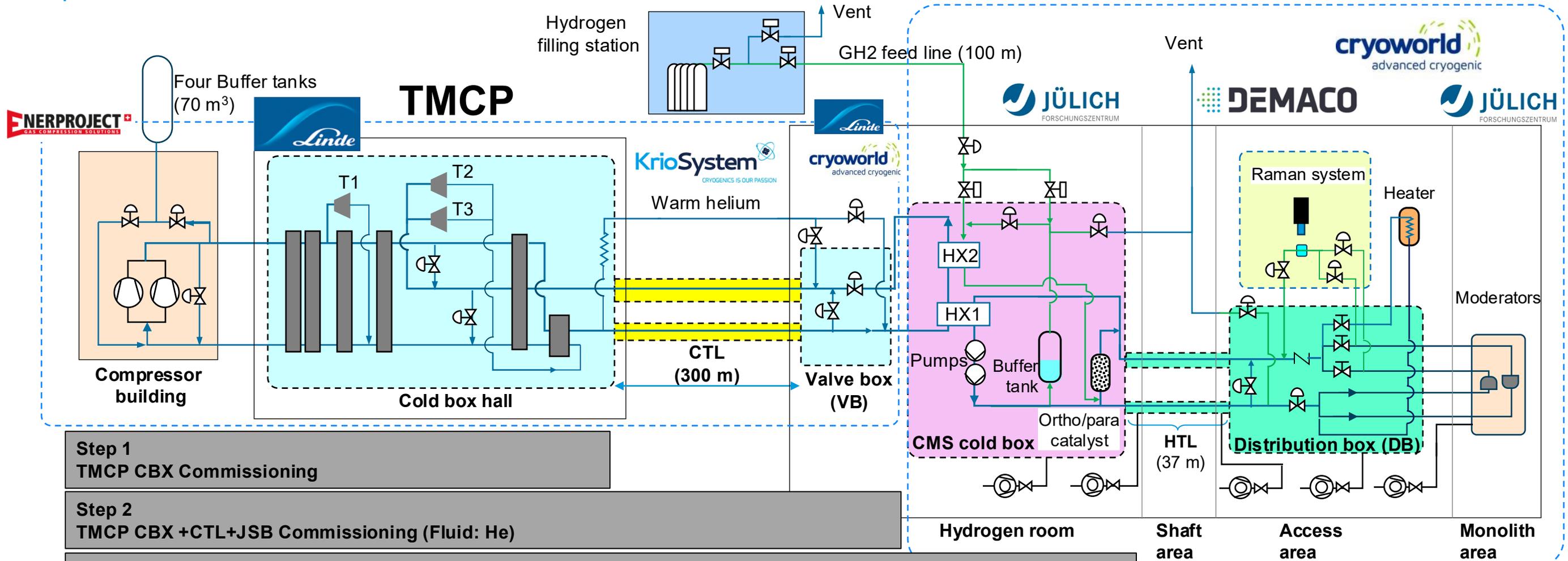
OPMS, sapphire window, Raman system



# CMS-TMCP system overview

## Installation and commissioning in steps

### CMS



**Step 1**  
 TMCP CBX Commissioning

**Step 2**  
 TMCP CBX + CTL + JSB Commissioning (Fluid: He)

**Step 3**  
 TMCP + CMS CBX Commissioning (first He, then H2)

**Step 4**  
 TMCP + CMS CBX + HTL + DB Commissioning (first He, then H2)

**Step 5**  
 TMCP + CMS CBX + HTL + DB + Moderators Commissioning (first He, then H2)

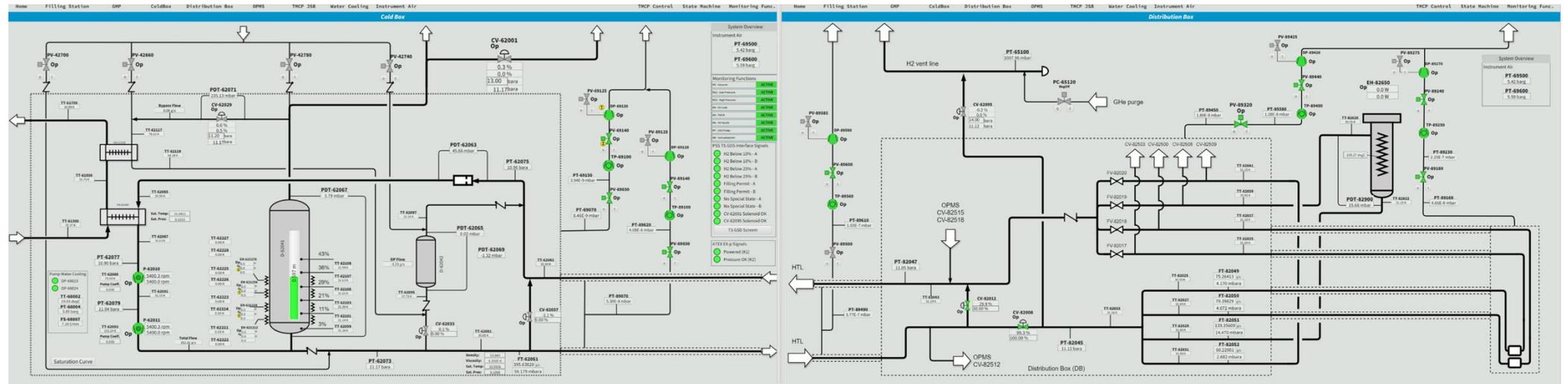
# Challenges of the Cryo moderator system



## Many commissioning steps

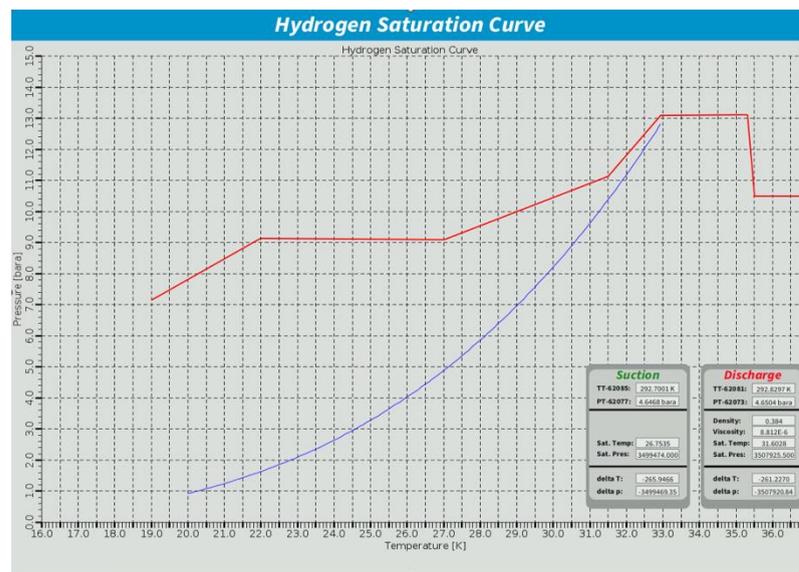
### Safety first

- H2 sensors, passive and active safety chain
- ATEX conformity incl documental effort
- Trainings for first responders, MCR, etc.
- Endless leak tests, sniffing, cleaning



### Cooldown strategy and parameters

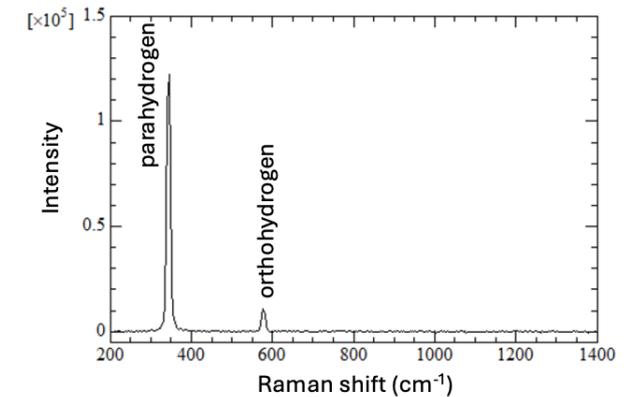
- Cooldown to ~40K in different steps overcoming NV cracking pressures
- Pressure increase and pseudo liquefaction
- Subcooling to 17K
- Keep HX dT low and temperatures stable w/o fluctuations even with long TLs



### Dynamic system response

- H2 heater testing and PID optimization
- JSB valve pre-emptive control for beam injection / beam trip
- Pressure control buffer response

### Raman measurements



# Current CMS status

...and what still needs to be done



## Operational issues

- TAO when operating with H<sub>2</sub> below 18.5K
- H<sub>2</sub> circulators to perform at optimum to avoid cold spots



## Remaining jobs

- Verify TAO mitigation effectiveness
- Fill activated catalyst in o/p converter
- Optimise Raman spectroscopy
- Verify target o/p ratio
- Training of all cryo operators

# Conclusions

Still some job to do but in good shape to meet high level milestones



ESS Cryogenics System ready for

- Beam On Dump 2 (BOD2, 2025)
- Neutron Factory Test (NFT, 2025)
- Beam On Target (BOT, spring 2026)
- Early Science and Steady State Operations (SSO)

## Thanks for your attention



[ess.eu](https://ess.eu)



[@ess.neutron](https://www.instagram.com/ess.neutron)



[@ess-neutron](https://www.linkedin.com/company/ess-neutron)



[@essneutron](https://www.youtube.com/channel/UC...)