EUROPEAN SPALLATION SOURCE

ESS Target Cryogenic System
European Cryogenic Days
CERN

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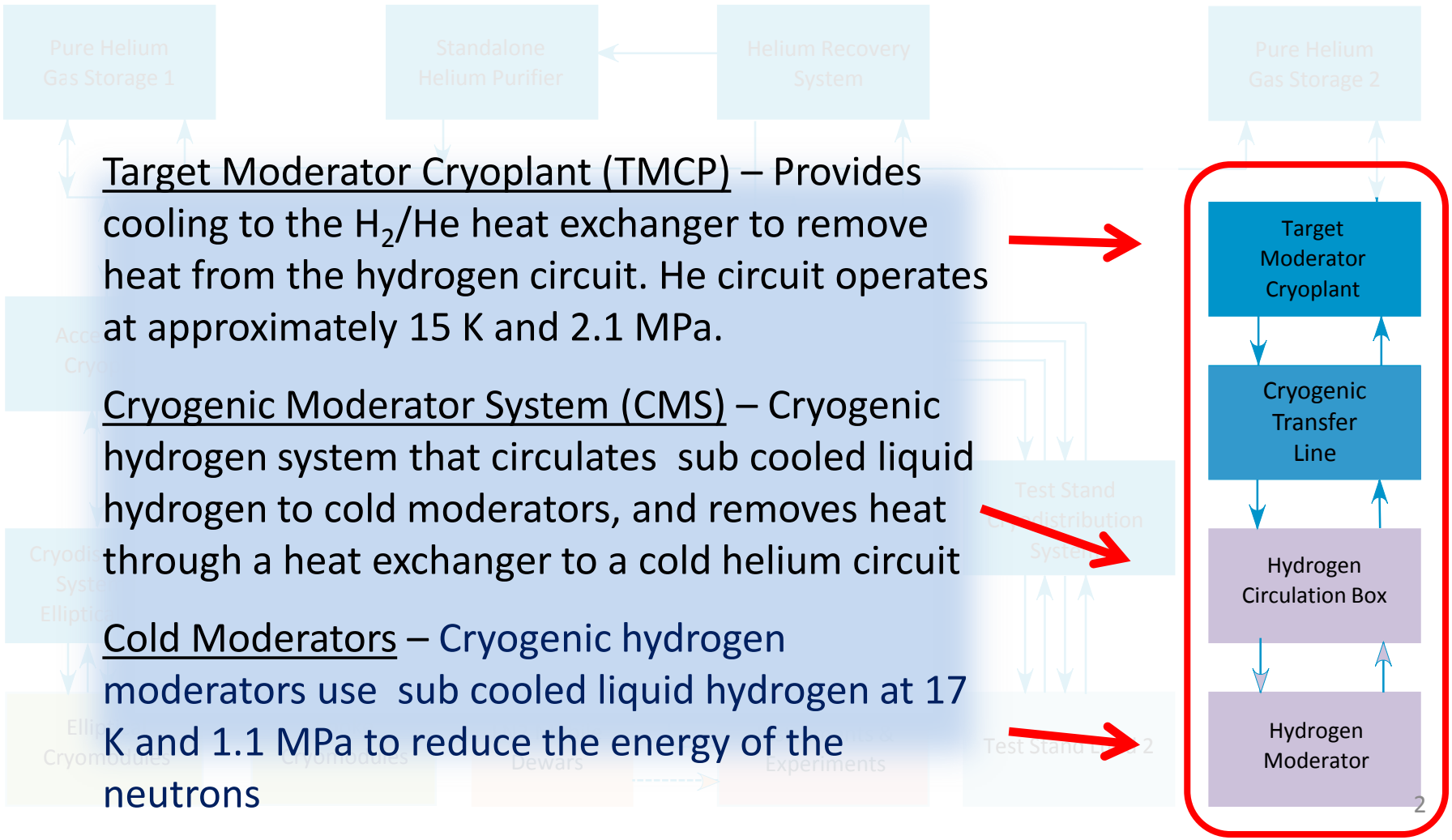
ESS Target Cryogenic Systems Overview

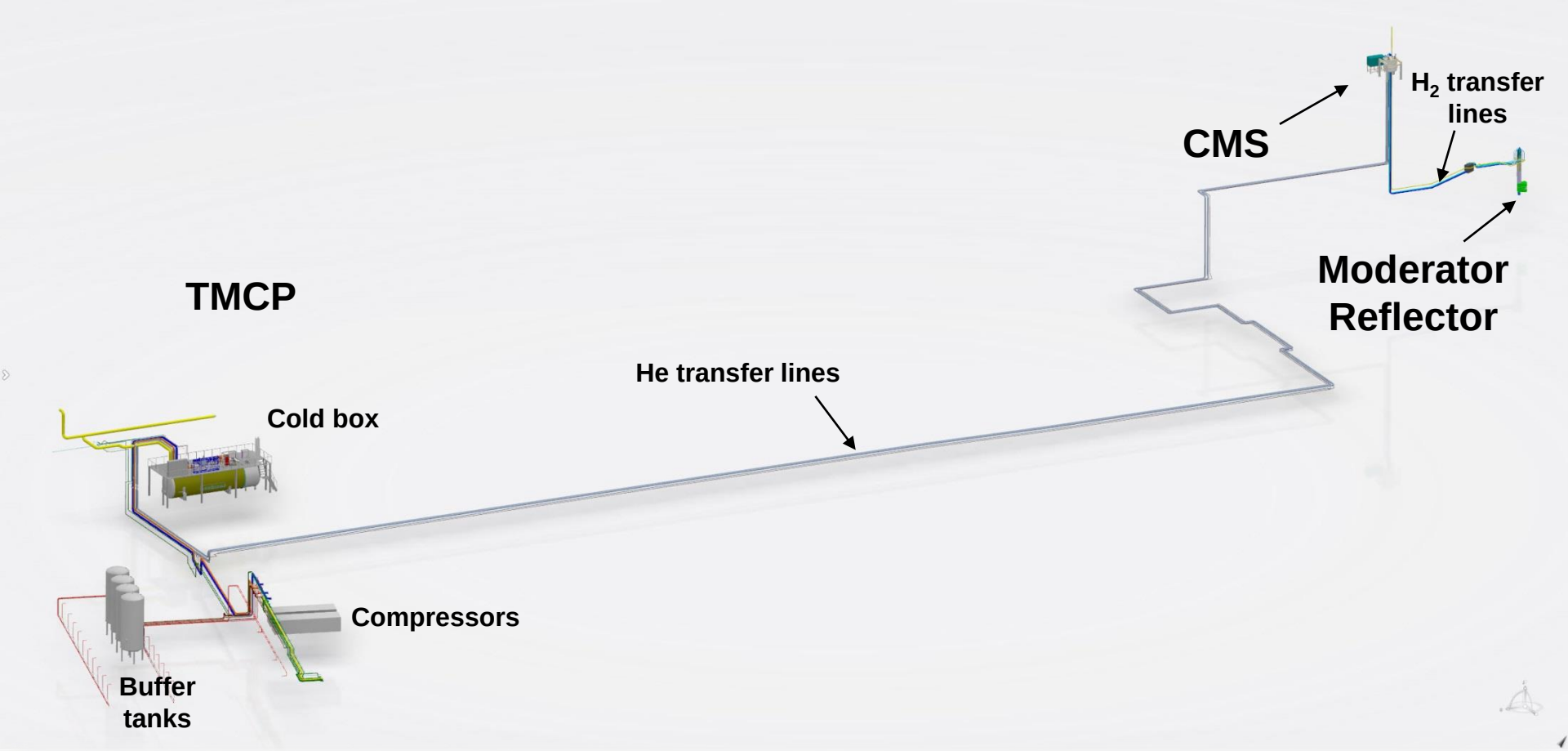


<u>Target Moderator Cryoplant (TMCP)</u> – Provides cooling to the H_2/He heat exchanger to remove heat from the hydrogen circuit. He circuit operates at approximately 15 K and 2.1 MPa.

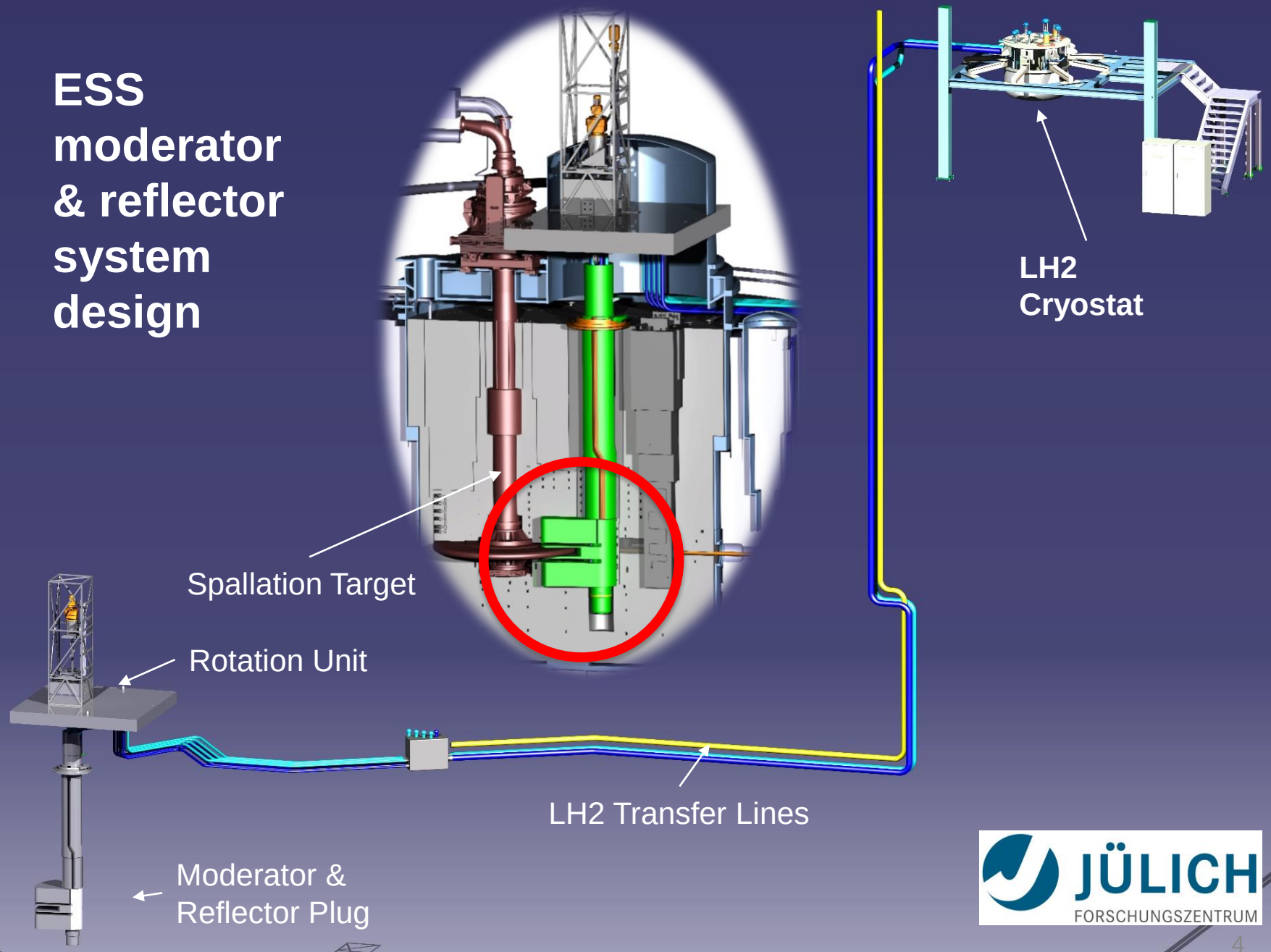
<u>Cryogenic Moderator System (CMS)</u> – Cryogenic hydrogen system that circulates sub cooled liquid hydrogen to cold moderators, and removes heat through a heat exchanger to a cold helium circuit

<u>Cold Moderators</u> – Cryogenic hydrogen moderators use sub cooled liquid hydrogen at 17 K and 1.1 MPa to reduce the energy of the neutrons

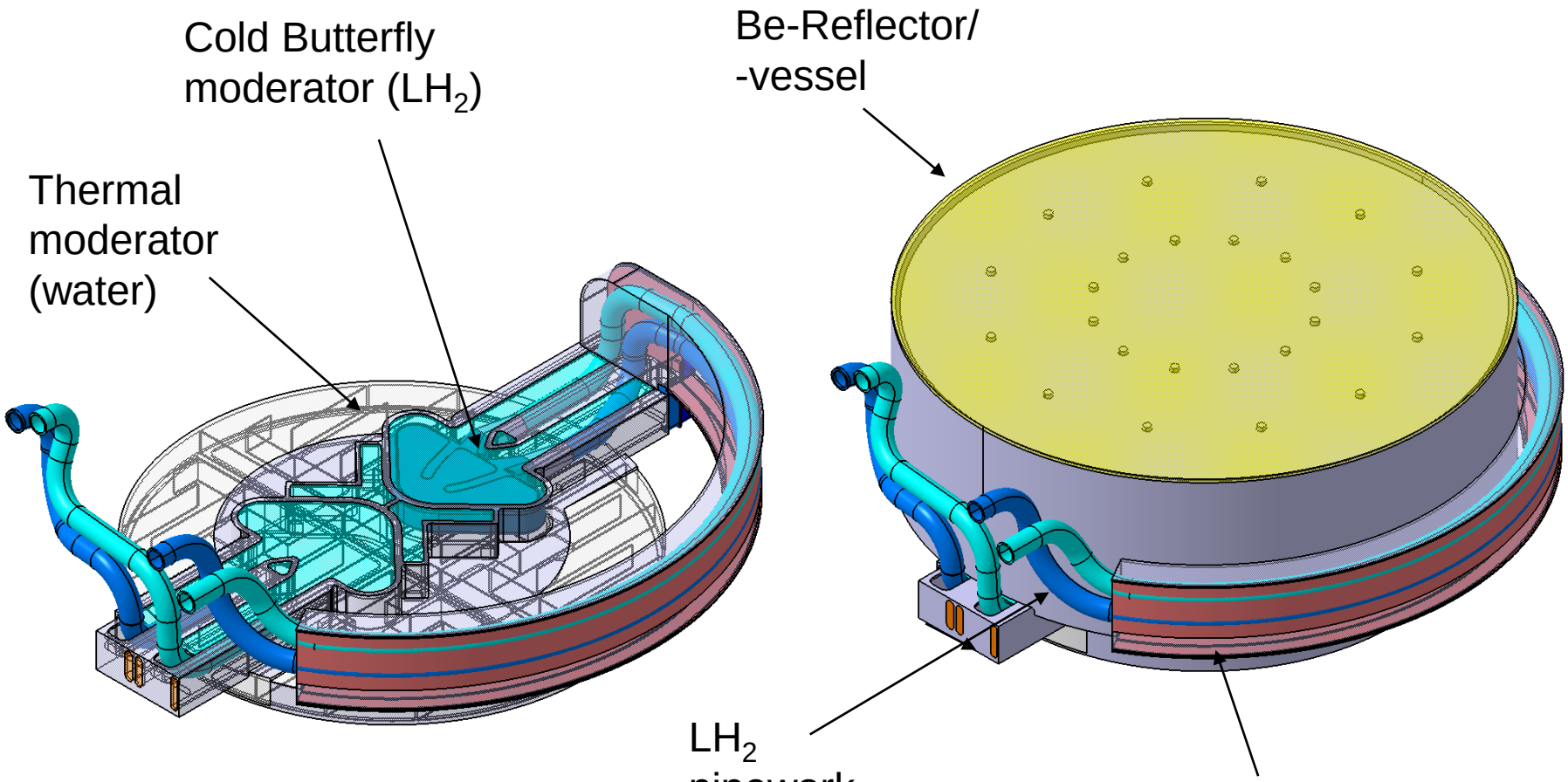
Integrated TMCP/CMS/MR system



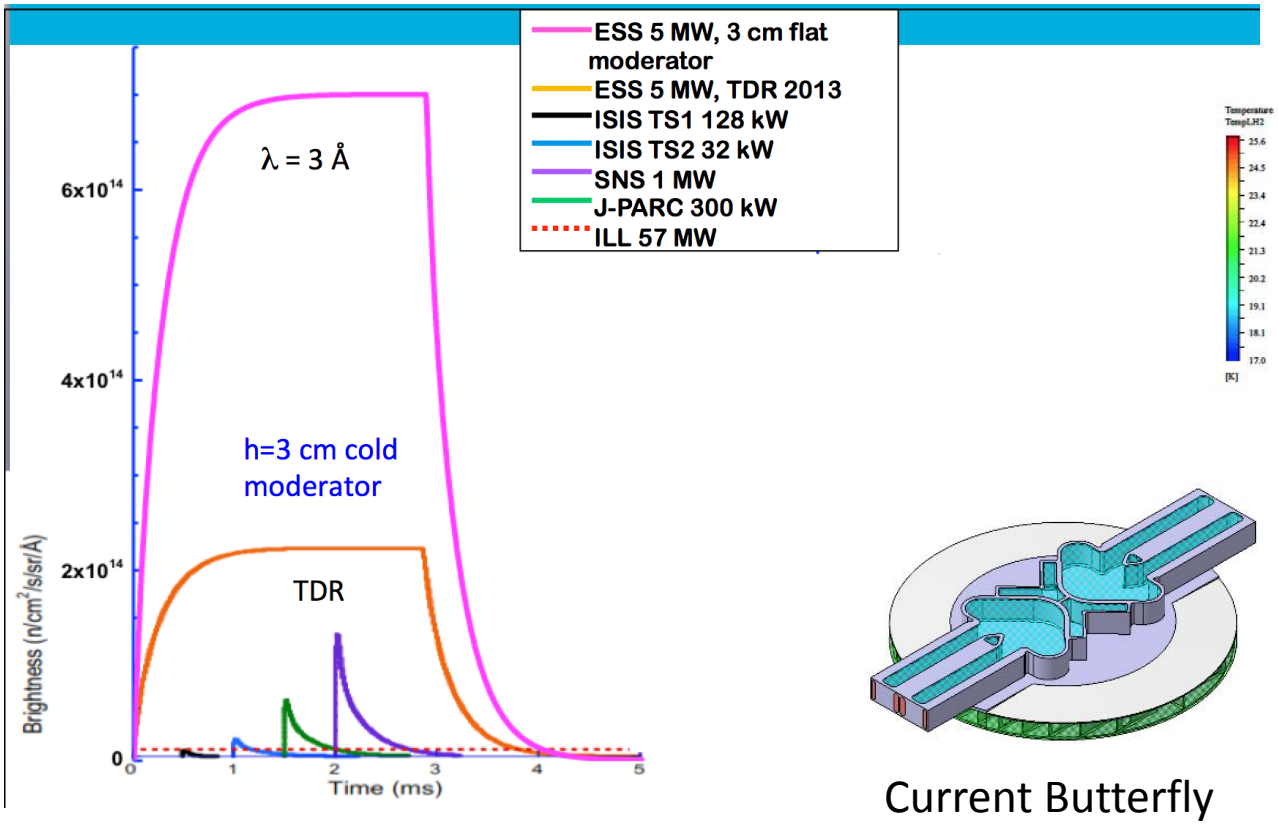
ESS moderator & reflector system design



ESS moderator & reflector unit design



ESS cold Moderator performance



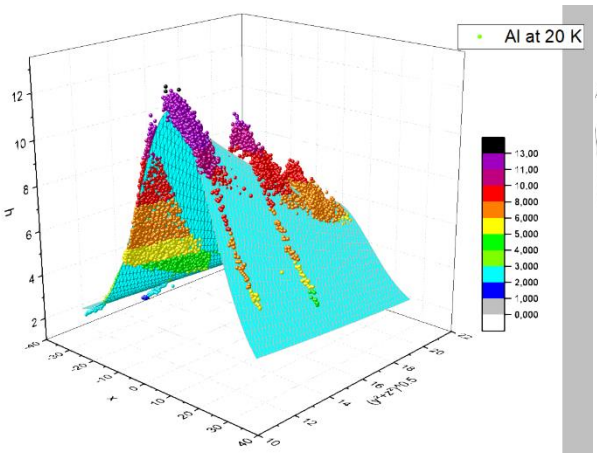
Source: ESS neutronic group

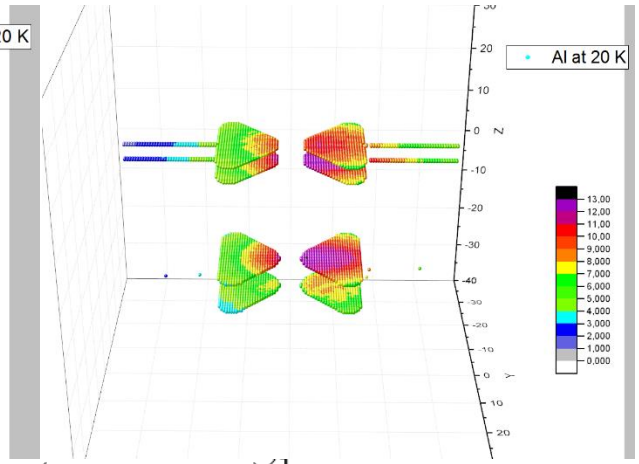
ESS TDR design

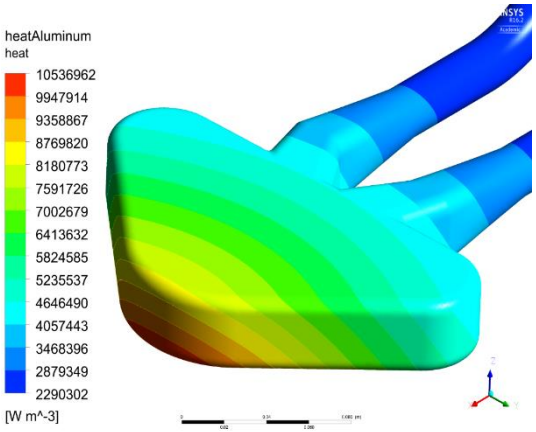
Current Butterfly design

Butterfly cold moderator provides significant increase in neutron brightness compared to ESS TDR design

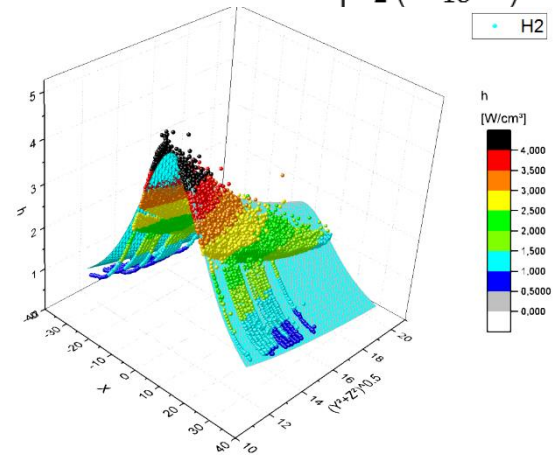
ESS cold Moderator heat input by neutrons

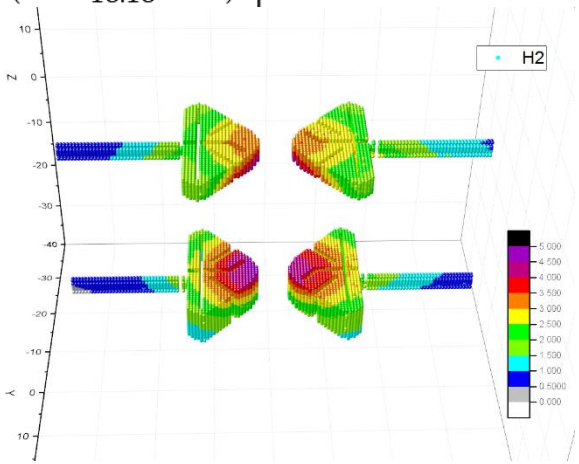


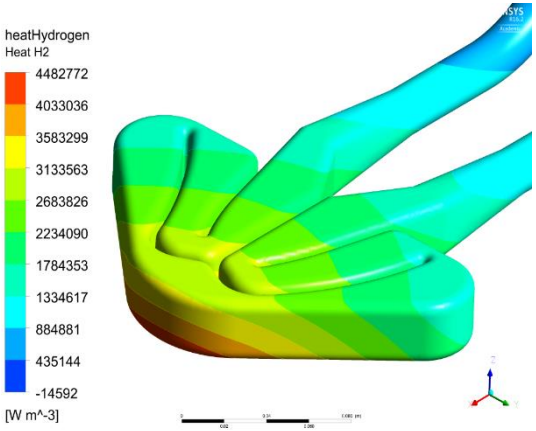




$$h(x,y,z) = 2.287 + 33.9exp\left[-\frac{1}{2}\left(\frac{x-5.34}{13}\right)^2 - \frac{1}{2}\left(\frac{\sqrt{y^2+z^2}+17.24}{18.18}\right)^2\right]$$





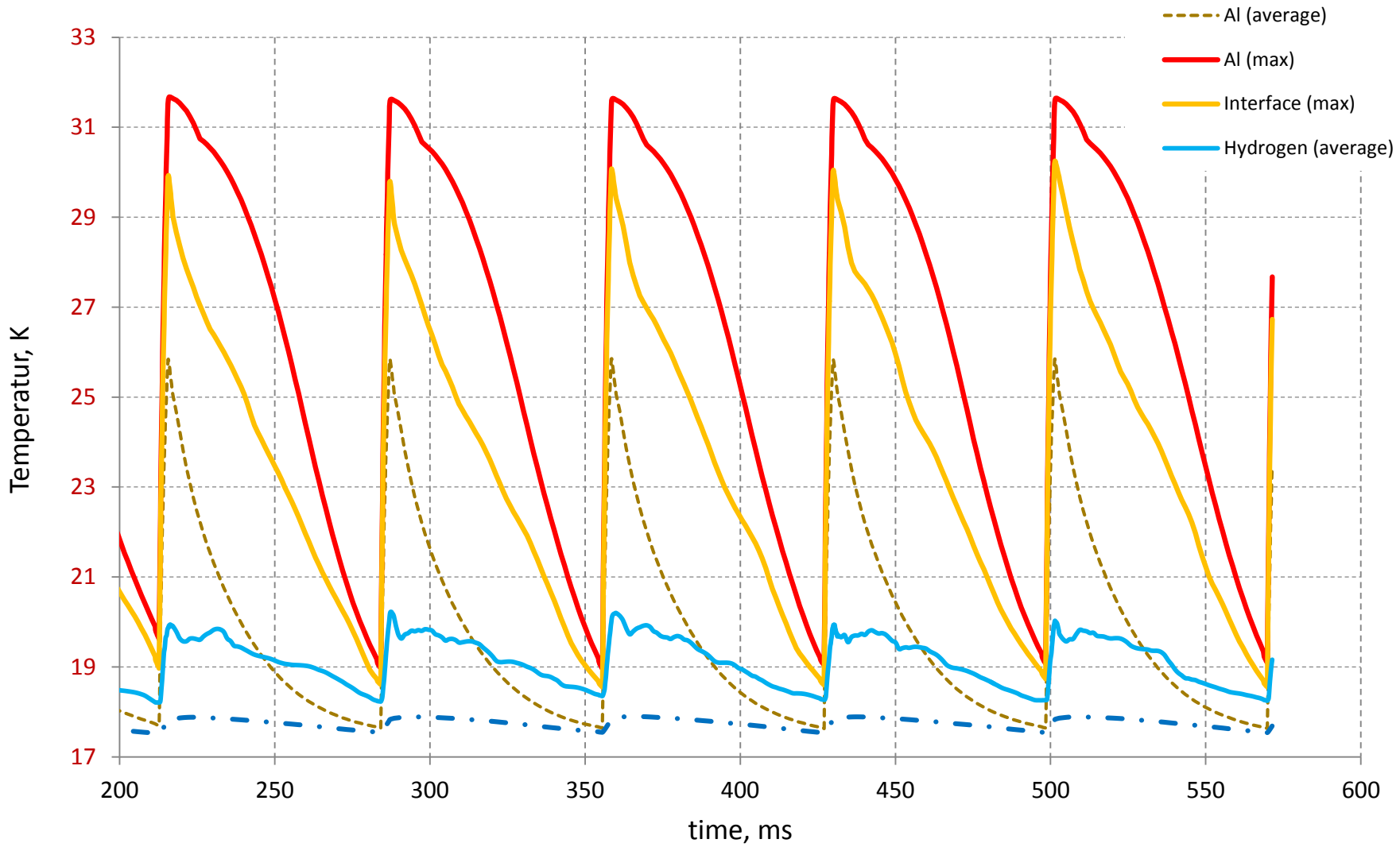


$$h(x,y,z) = -0.17317 + \frac{101.78613}{\left[1+\left(\frac{x-0.42345}{18.20385}\right)^2\right]\left[1+\left(\frac{\sqrt{y^2+z^2}+3.56612}{3.34324}\right)^2\right]}$$

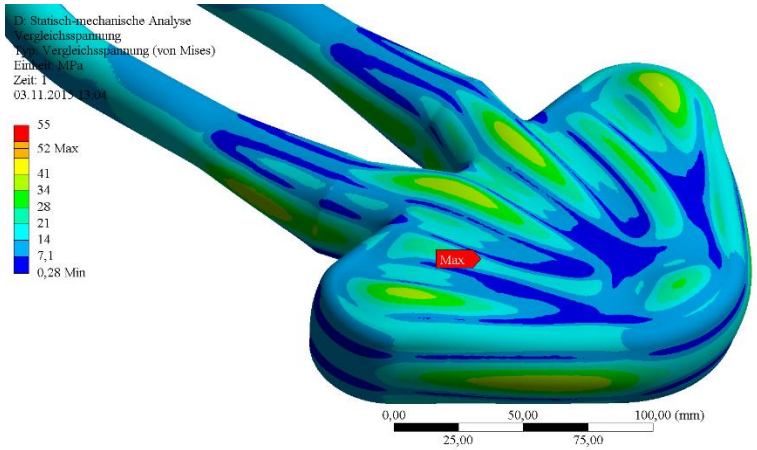
∑ upper cold Moderators ≈8.0 kW

ESS cold Moderator fluid thermal dynamics

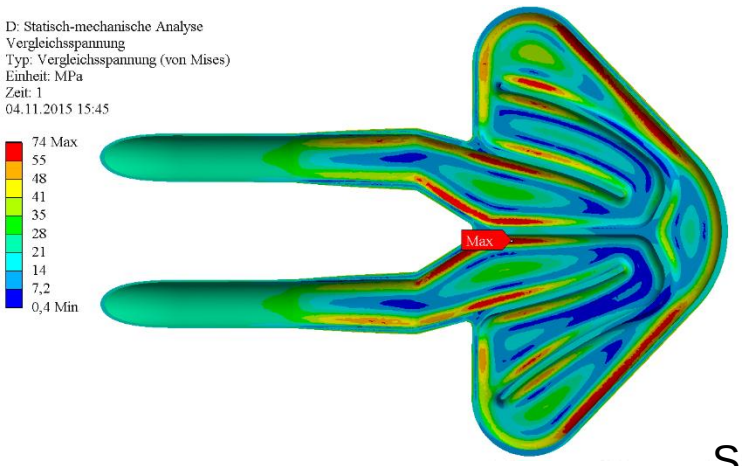
(temperature variation during 350 ms pulse)



ESS cold Moderator structural mechanics

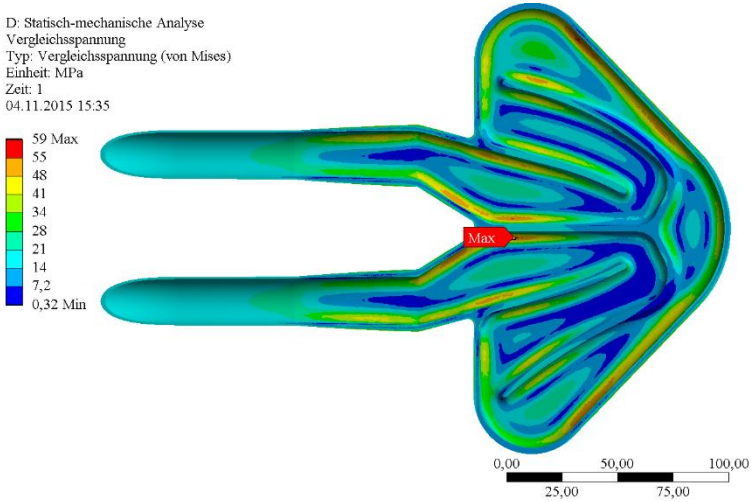


Stress @15 bar / 20 K **operation case**

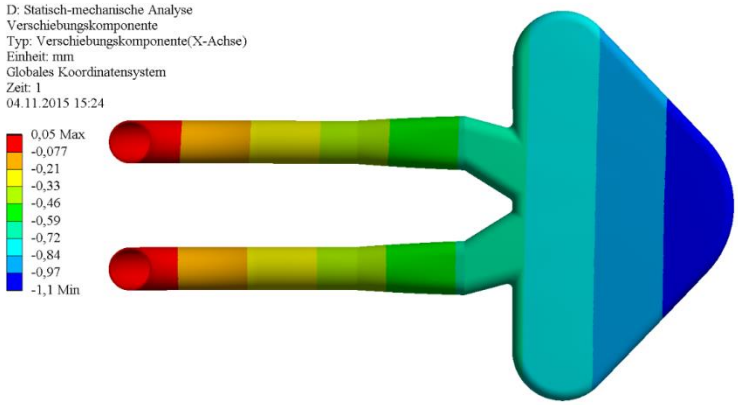


Stress @21,45 bar / 300 K **test case** S>55

S=55MPa
(RCC MRx)

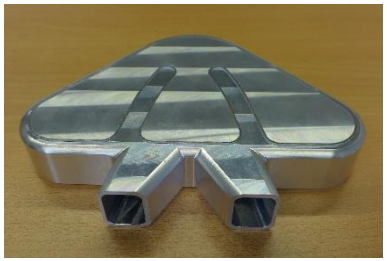


Stress @17 bar / 20 K **design case** S<=55 MPa

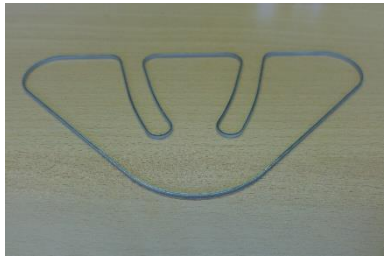


Deformation (without Invar)

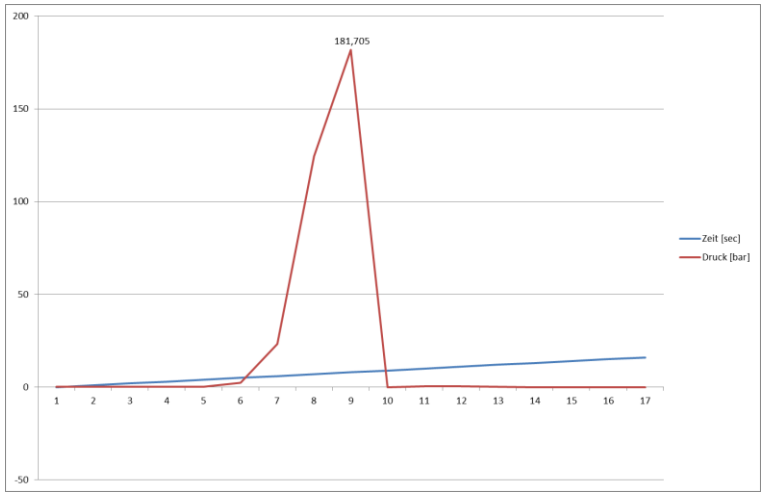
ESS cold Moderator manufacturing test



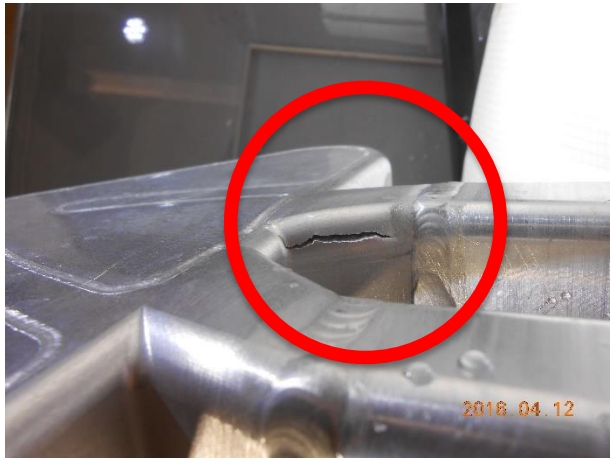
Mounted Al-6061-T6 pieces bevor eBeam welding



Weld filler



First burst test with water / burst pressure 181 bar / design pressure 17 bar



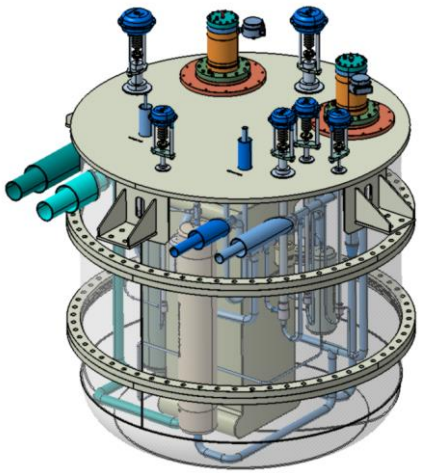
CMS Specification

Main task for the Cryogenic Moderator System.

The Target Station shall use para-H_2 material as cold moderator coolant such that the neutronic performance will sustain the required brightness while the technical risk will be residual thanks to the available experience using this material.

- Expected Heat load neutronic: 19.0kW incl. Contingency margin
- Expected Heat load static: 9.8kW
- Hydrogen content in system: 22kg liquid hydrogen
- Working Temperature: 17-20.5K
- Working pressure: 1.1MPa
- Design pressure: 1.7MPa
- Pressure drop: ~0.2MPa
- Expected mass flow: 1000 g/s
- Ortho-Para cathalyst: Oxisorb placed in a by-pass line
- OP ratio: >99.5%
- In line measurement: Raman spectroscopy ahead and after moderator
- Pressure control: Active buffer, expansion vessel.

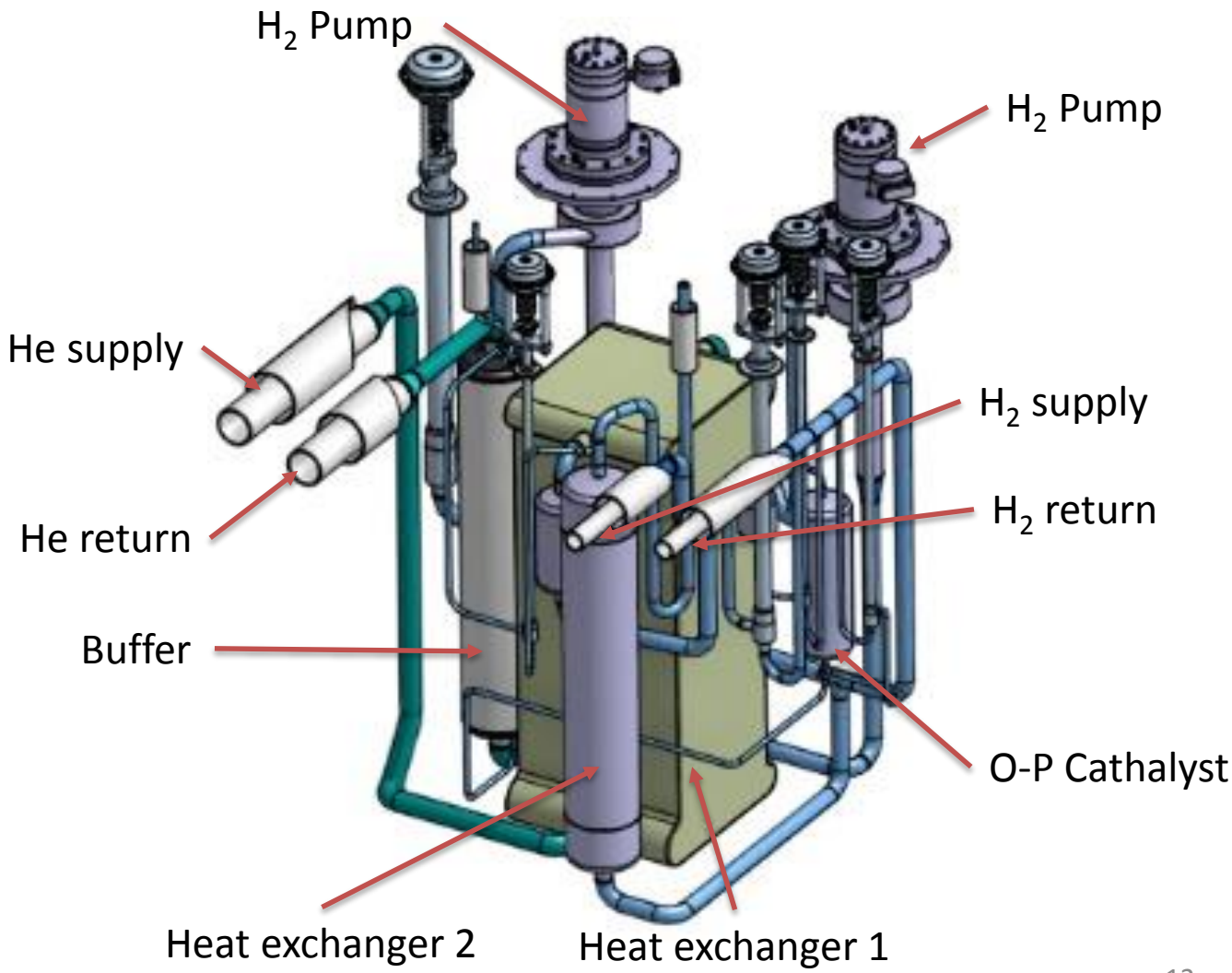
CMS Overview



Cryostat

Weight 3700kg
Ø: 1800mm
H: 2000mm

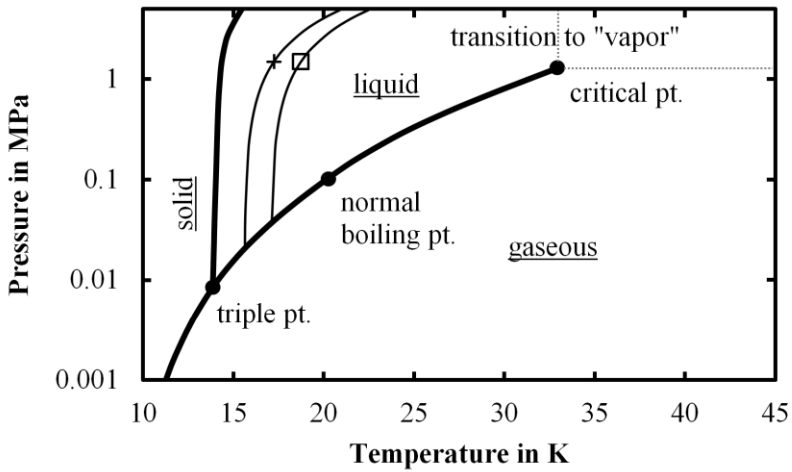
Pipes and components insulated with MLI

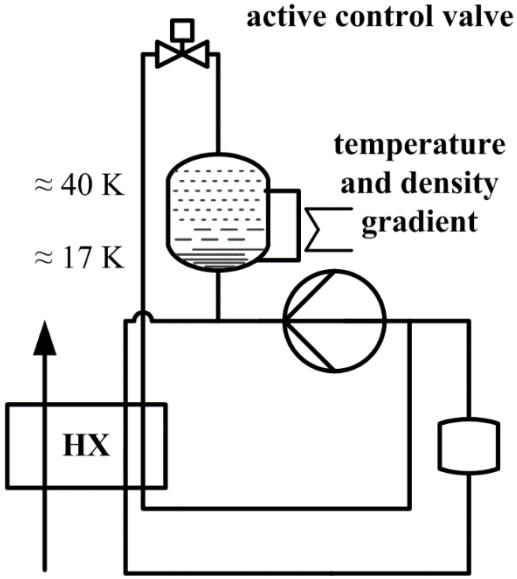


CMS Overview, buffer vessel

Pressure Control System – Buffer Vessel

A vertical buffer vessel with an axial temperature and density gradient will store/release hydrogen mass of the main loop in case of beam increase/decrease.





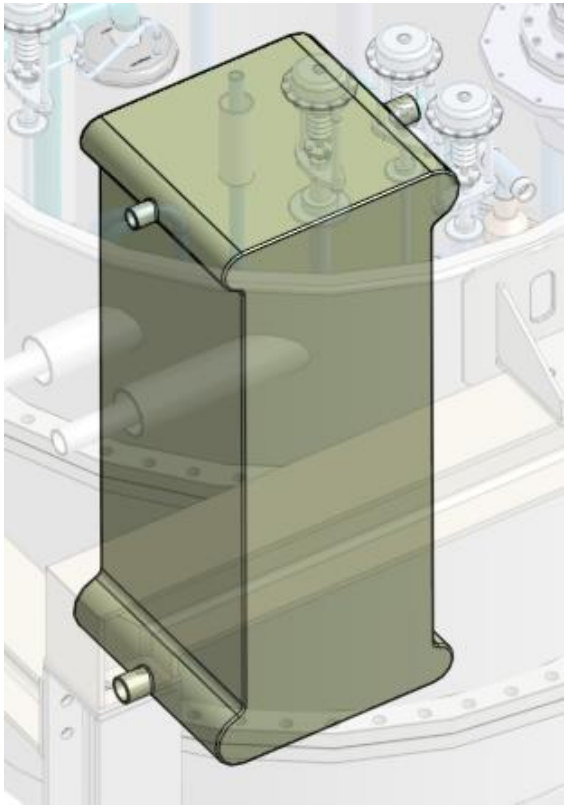
Small mean temperature variations can cause severe pressure fluctuations

H_2 at < 20 K almost incompressible

H_2 at > 35 K becomes compressible

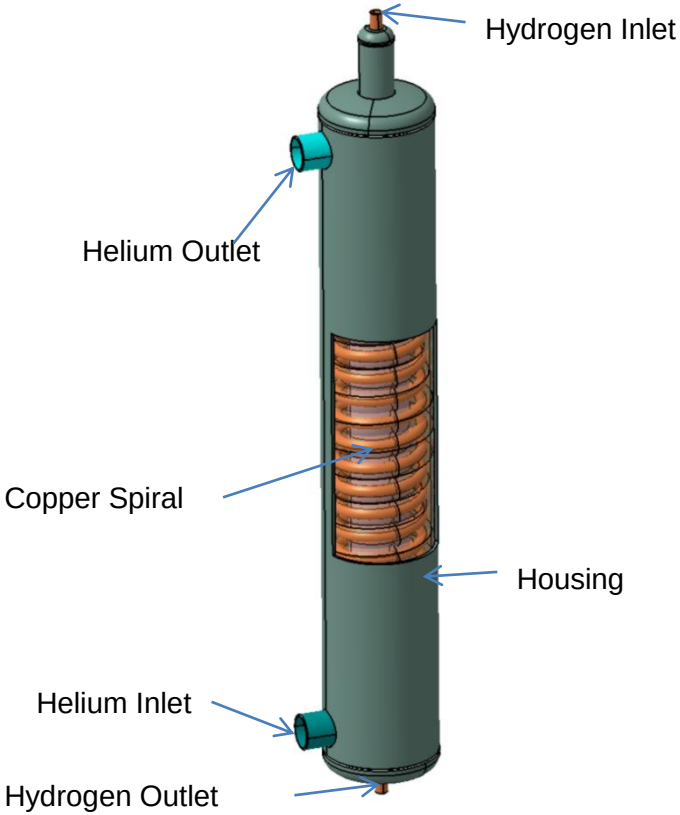
-> buffer mitigates pressure variations

CMS Overview, heat exchanger 1 & 2



Heat exchanger 1:
Aluminum plate fin exchanger
Used to liquefy the hydrogen during fill and maintain temperature during operation

Heat exchanger 2:
Fin tube exchanger
To liquify GH_2 from buffer and main fill line during operation.



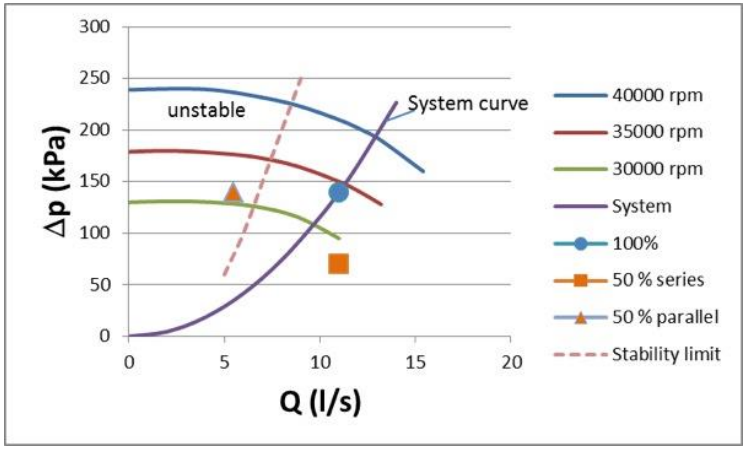
CMS Overview, hydrogen pumps

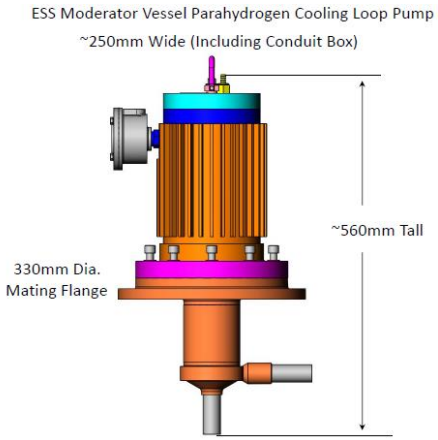
Hydrogen Pumps

Serial setup with 2 pumps

Each pump provides full mass flow but shares the pressure drop

If one pump fails the second pump will step up and compensate for the full pressure drop.

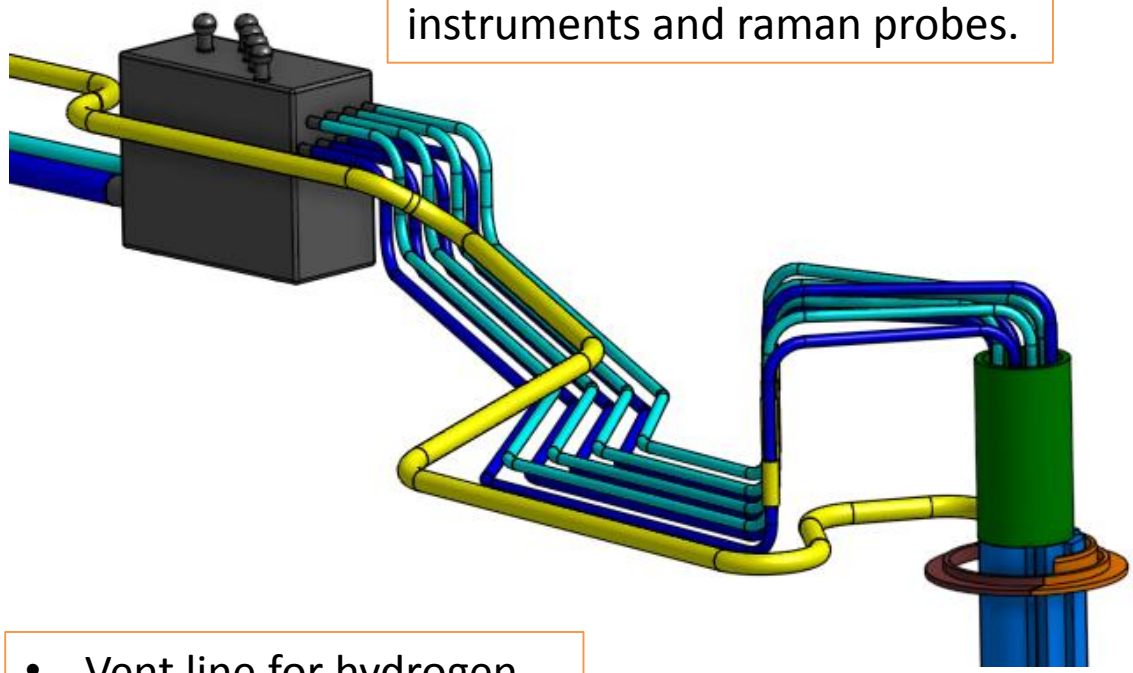




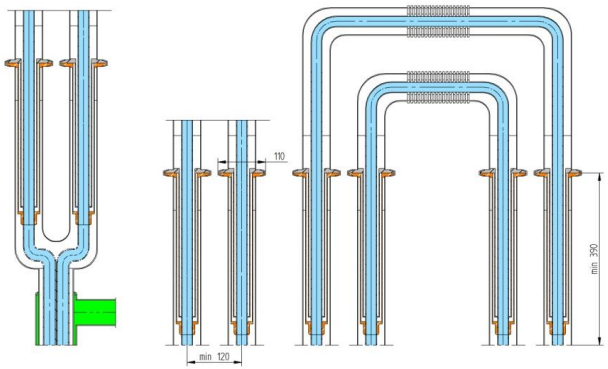
Equipment spec pumps	
Flow rate	Q_{max}: 1000g/s @17K
Working Temperature media	17-300K
Working pressure	1.1MPa
Set up	Serial connection, Both pumps at full flow, shared pressure drop
Fail mode	1 pump, 100% flow
Pressure drop estimated	ΔP: 0.1/0.2MPa
Media	Gaseous, supercritical and liquid H_2
Control	Frequency Controlled motor

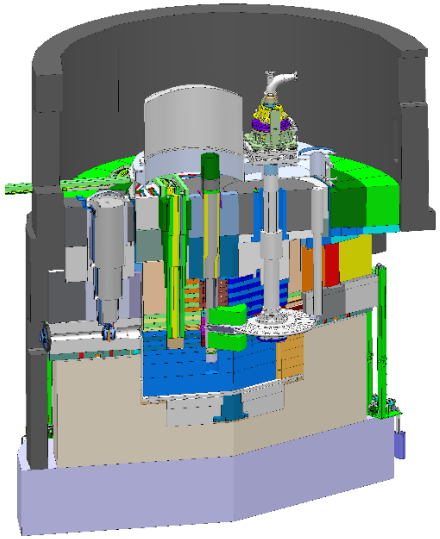
CMS Overview
connections to moderator plug

Manifold includes valves, instruments and raman probes.



Jumper connections with bayonet couplings inside the monolith.





- Vent line for hydrogen
- Connected to safety relief valves and manual release valves
- Purged with He/N_2

TMCP Design Drivers

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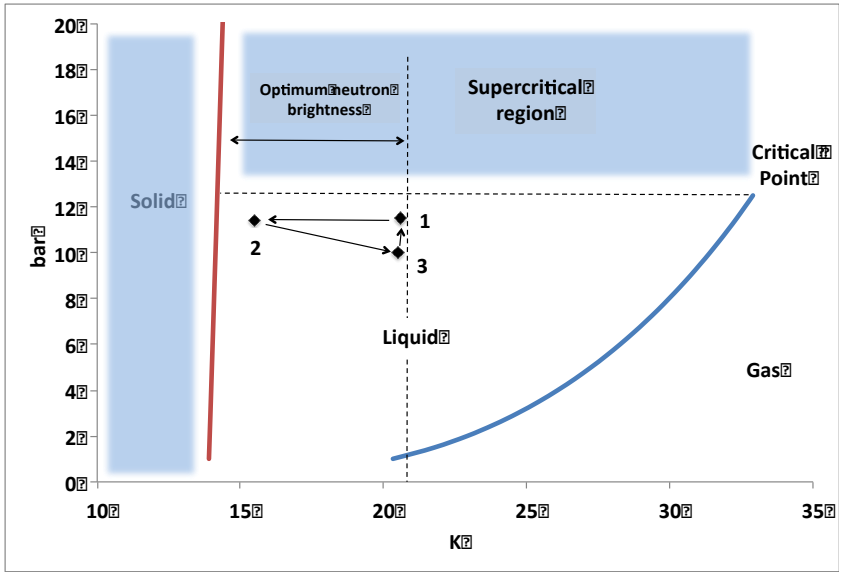
Unique attributes of the TMCP

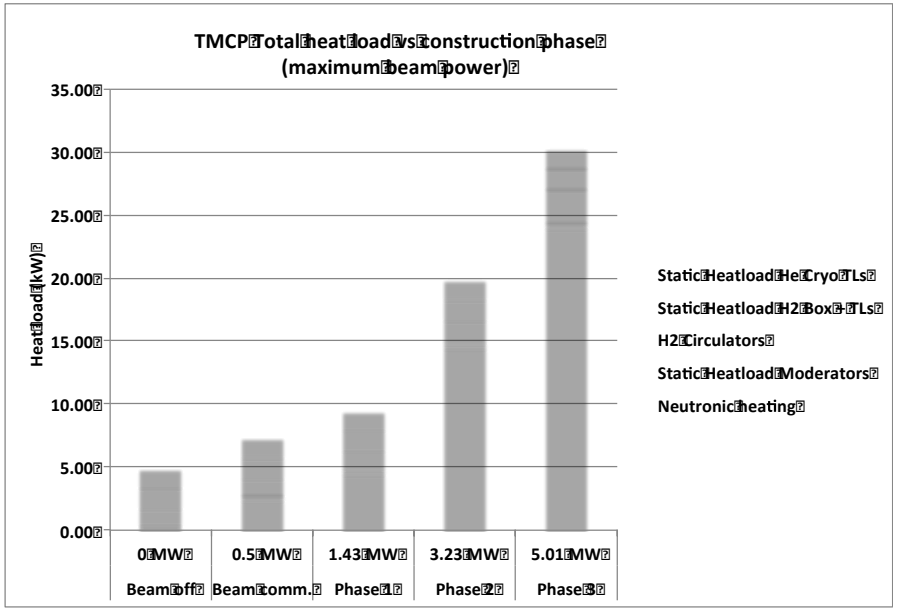
- High maximum heat load: 30 kW at 15 K
- Wide range of dynamic heat loads: 5-30 kW
- 6 years from 1st protons on target to full power operation
- Multiple operating modes
  - Steady state – 15-100% of capacity
  - Transient – Cool down and warm up
  - Switching – Short term fast changes
- CMS requires narrow temperature range: 17-21 K
- High heat load and narrow temperature range means high helium mass flow rate
- Long cryogenic transfer lines results in high helium inventory - ~490 kg total

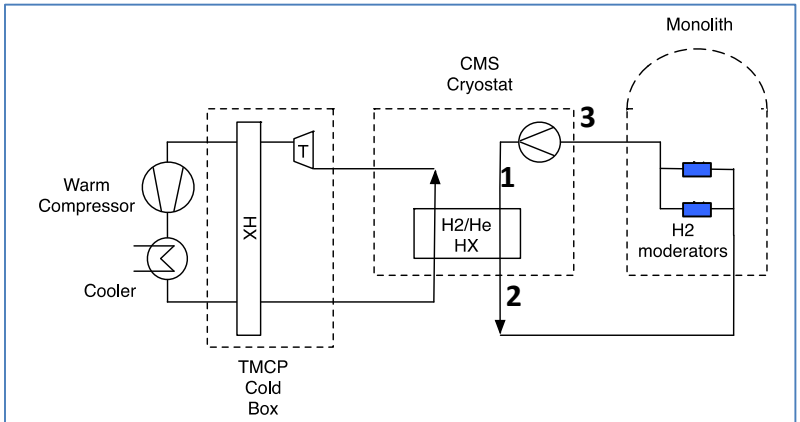
TMCP Design Drivers

Narrow operating range

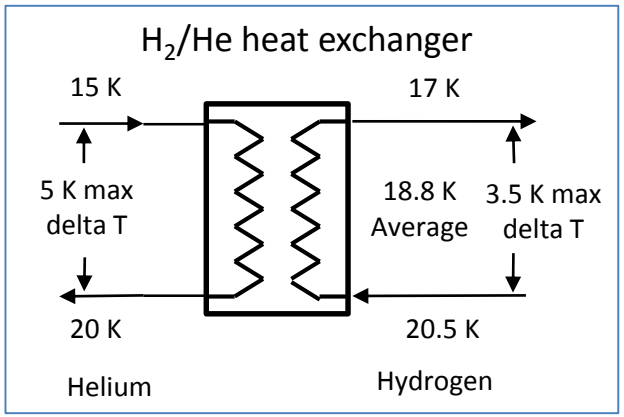


Large variation in heat load



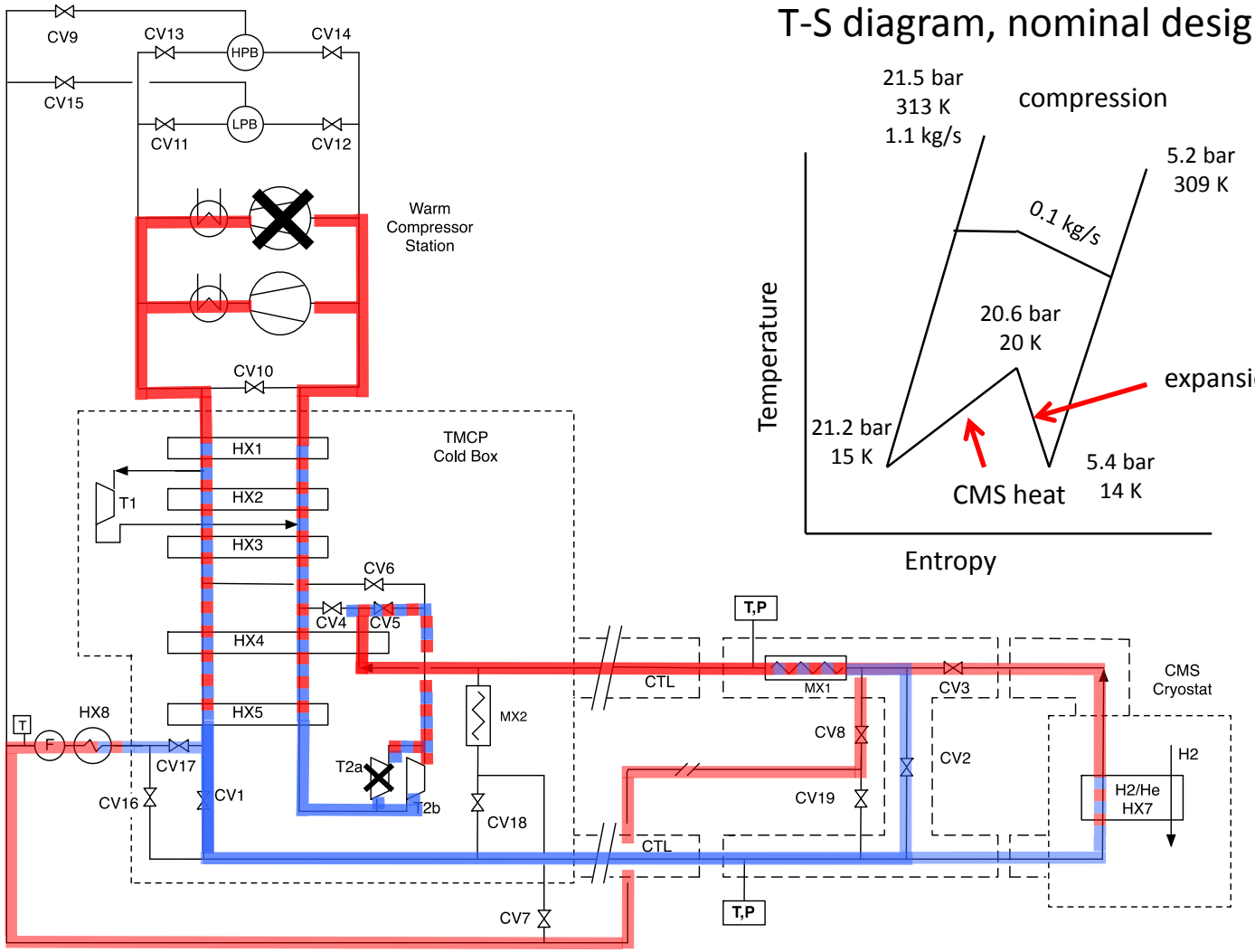


Closed loop modified Brayton cycle



TMCP Process Design Description

Operating modes



T-S diagram, nominal design

Highlights

- Butterfly design successfully modeled, manufacturing process proven
- Butterfly design promises significant improvement in neutron brightness
- CMS Critical Design Review passed, detailed design on-going
- CMS buffer unique robust design, proof of concept testing planned
- CMS long lead items (pumps, heat exchanger) procurement cycle started
- TMCP contract award made May 2016
- Project on schedule
  - TMCP commissioning complete 4Q18
  - CMS installation complete 1Q19
  - Integrated testing 1-2Q19

Finis