Cryogenics at the ESS – Focus on sc linac CDS commissioning

European Cryogenic Days, GSI, Darmstadt 2023

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2023-03-29

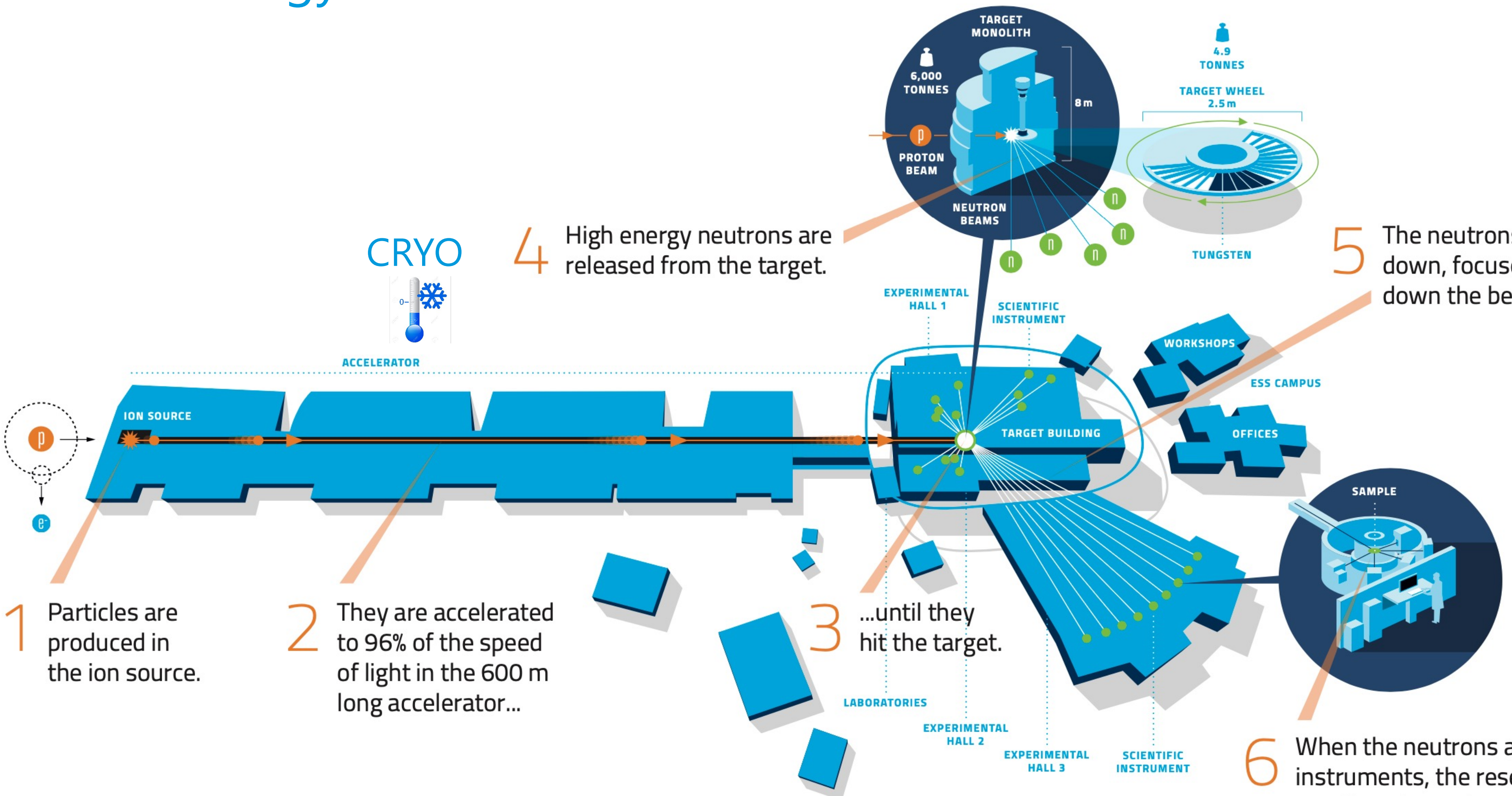
European Spallation Source

Reason for being

Enable scientific breakthroughs
in materials research related to energy, health, the environment, industry, manufacturing and the natural world to address some of the most important societal challenges of our time

How it works

The technology



1 Particles are produced in the ion source.

2 They are accelerated to 96% of the speed of light in the 600 m long accelerator...

3 ...until they hit the target.

CRYO

4 High energy neutrons are released from the target.

5 The neutrons are slowed down, focused and sent down the beamlines.

CRYO

6 When the neutrons arrive at the instruments, the researchers can use them to explore materials down to an atomic level.

CRYO

Agenda

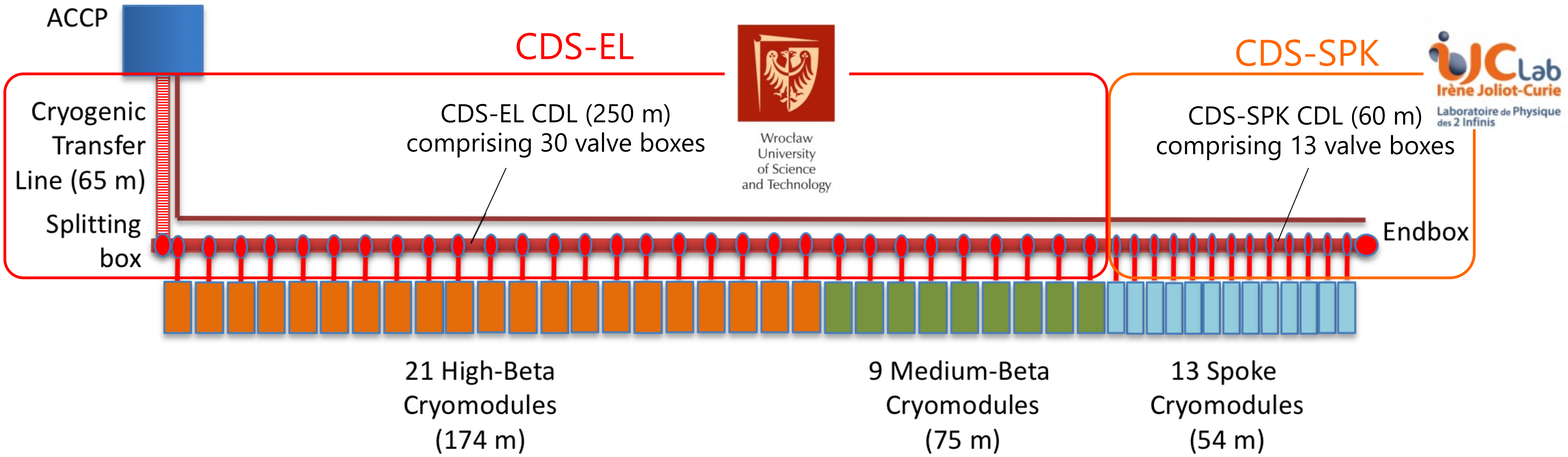
1 Introduction Cryogenic Distribution System for the superconducting linac

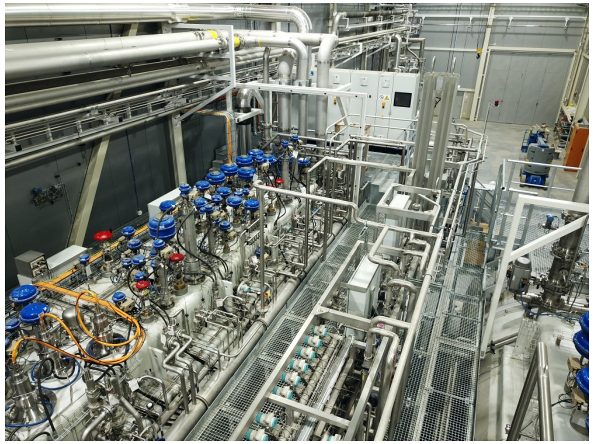
2 1st CDS cooldown, heat loads and detected issues

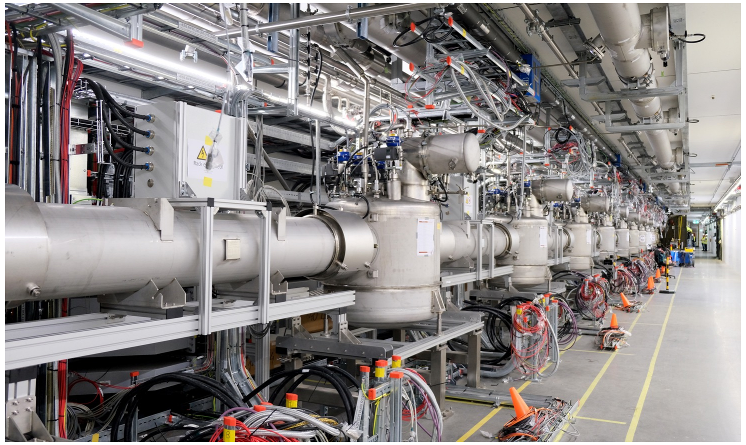
3 Cold compressors and endbox issues

4 Repair activities and summary

Cryo distribution system for the sc linac

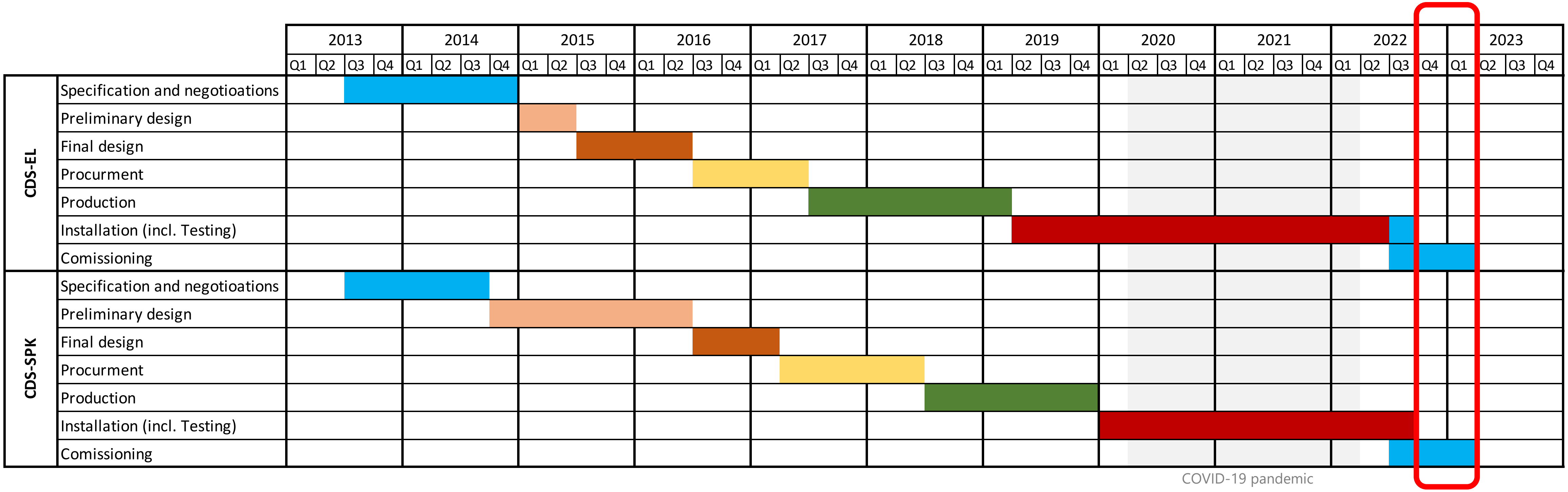






CDS testing and commissioning

Rough outline



Credit: Jarek Fydrych, ESS

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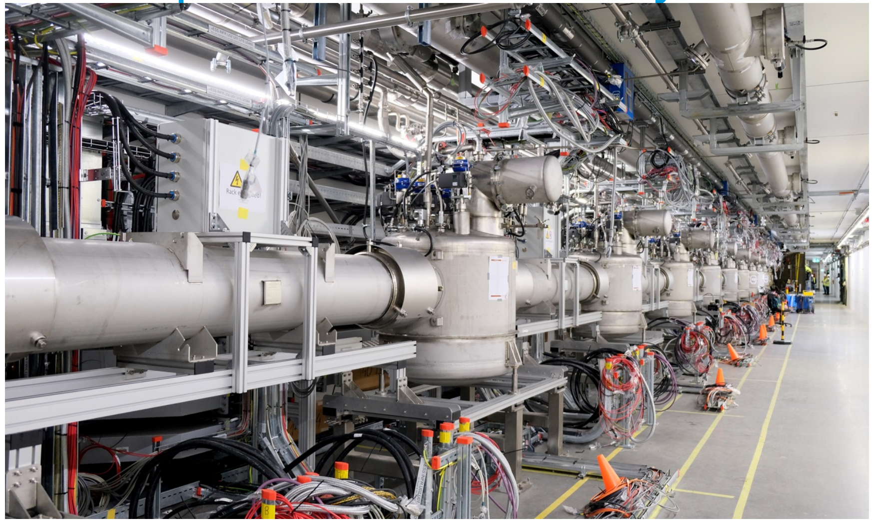
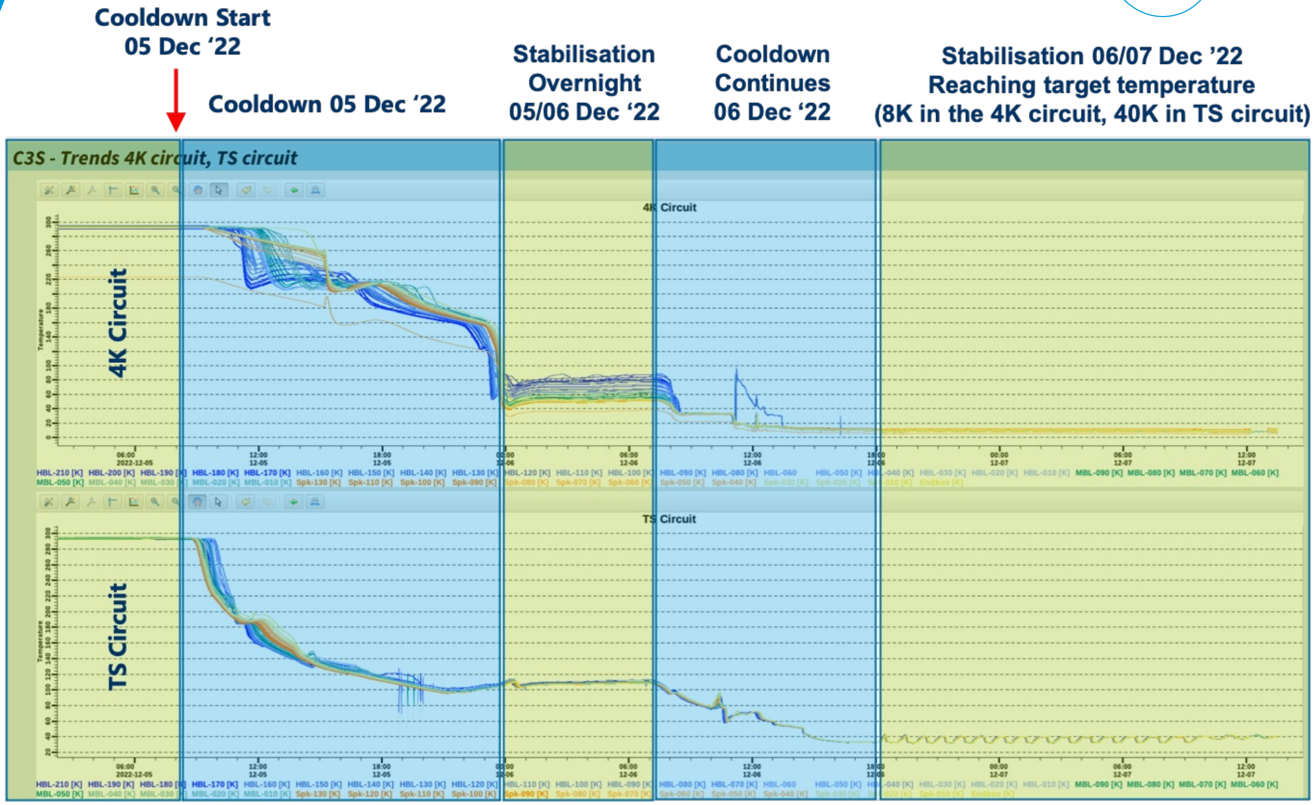
1st Cooldown, heat load testing and detected issues

Cooldown of CDS in December 2022

As published internally and externally





… and then the fun just started…

Finding issues during nominal operation

Ice on valves, pipe branches, vibrations, leaks etc.

11 x SVs in 4.5K supply open way before 3 bar(g)

Vibration and noise on up to 25/30 CDS-el VBXs

Plenty of leaky valves over the seat

CDS overall heat load

Heat load determination methodology

$$\dot{Q}_{meas} = \dot{m}\left[h_o\left(T_o,p_o\right) - h_i\left(T_i,p_i\right)\right]$$

$$\dot{Q}_{meas} = \dot{Q}_0 + \dot{m}c_p\Delta T_{err}$$

Where $\dot{Q}_0$ is the constant real heat load, C_p is the constant specific heat capacity (~5.76 J/(g.K)), ΔT_{err} is the systematic error of the inlet and outlet temperatures.

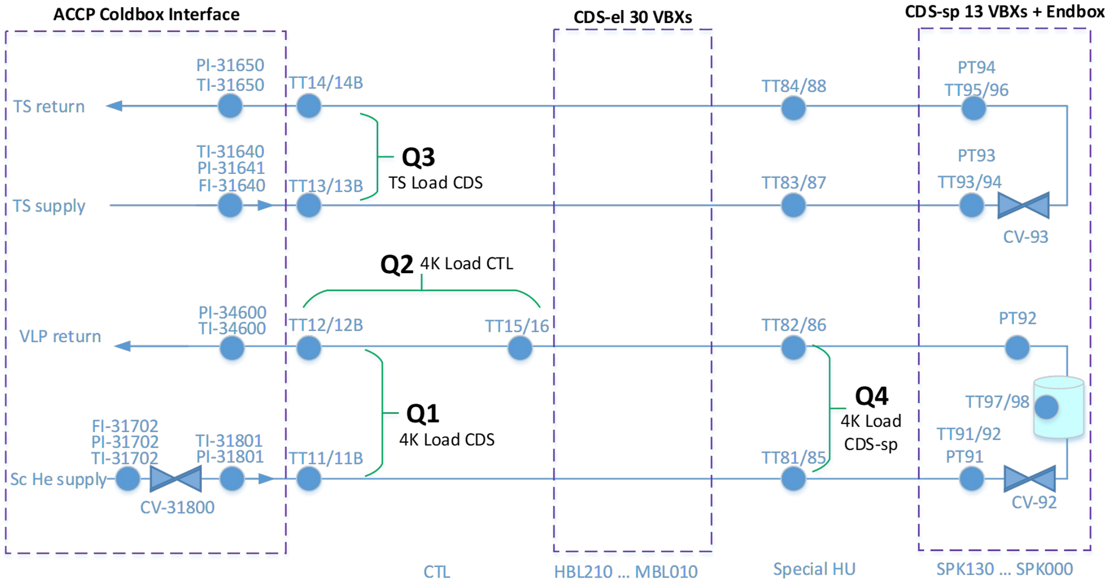
$$\frac{\dot{Q}_{meas}}{\dot{m}} = \dot{Q}_0\frac{1}{\dot{m}} + c_p\Delta T_{err}$$

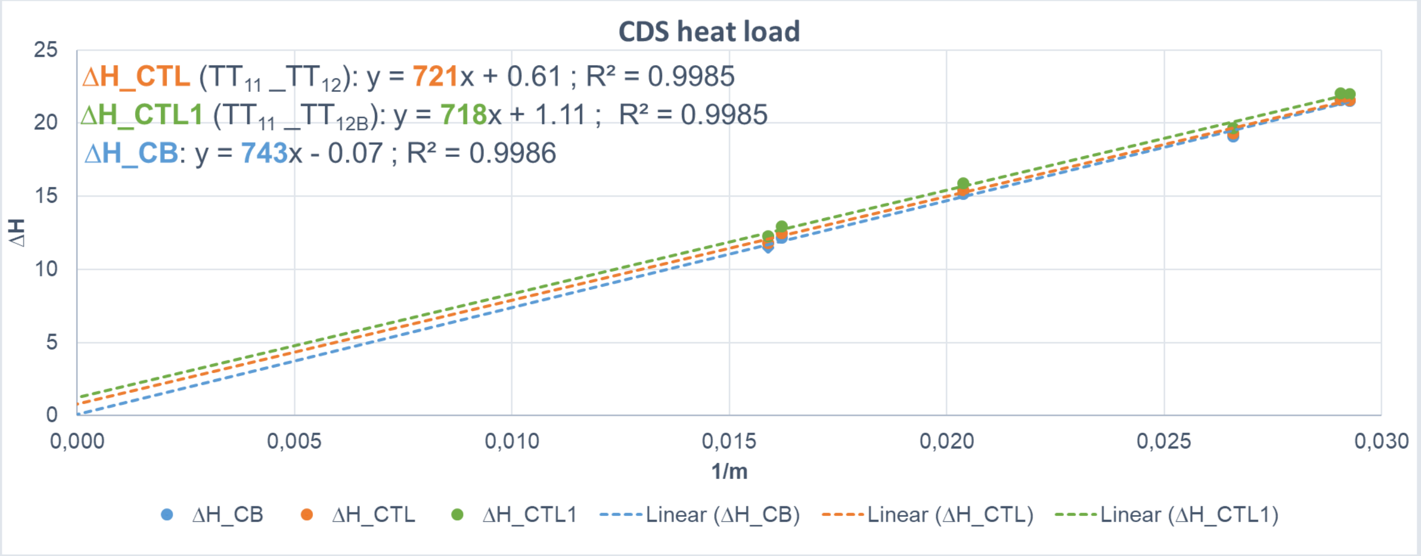
$$\Delta H = \dot{Q}_0\frac{1}{\dot{m}} + c_p\Delta T_{err}$$

$$y = A\,x + B$$

$$y = \Delta H,\ x = \frac{1}{\dot{m}},\ A = \dot{Q}_0$$

Credit: Nuno Elias, Jianqin Zhang, ESS





TAOs on VLP return valves in CDS-el

… in function of 4.5K supply valve opening

(1) MBL-020

(2) MBL-090

(3) HBL-030

(4) HBL-110

(5) MBL-020

(6) MBL-090

(7) HBL-030

(8) HBL-110

Test 1#: 4K supply valve in CDS-el CV-03=20%
- Strong TAO
- Ice on >50% of all VLP return valves CV04
- Measured heat load Q1: ~740 W

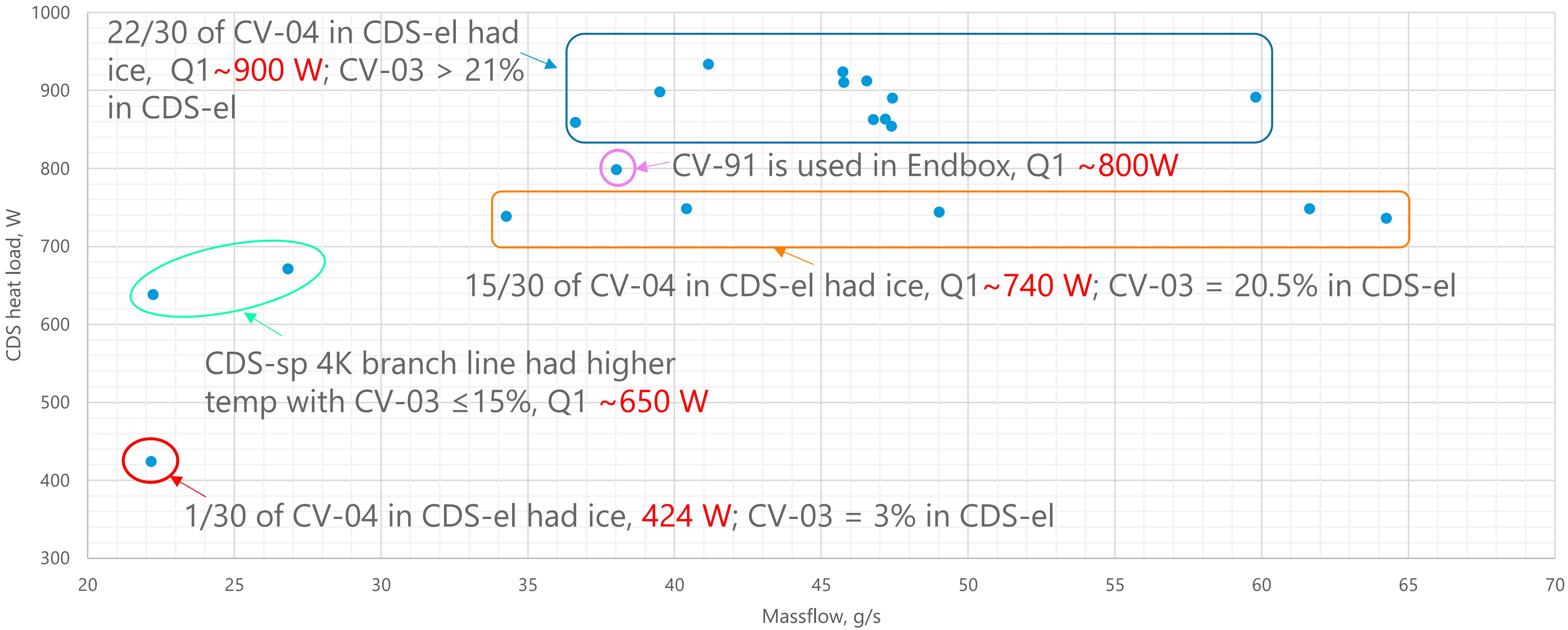
Test 2#: 4K supply valve in CDS-el CV-03=3%
- Much reduced TAO
- Ice melted on almost all VLP return valves CV04
- Measured heat load Q1: ~425 W

Otherwise constant conditions (same supply temperature, pressure, other valves opening etc.)

CDS overall heat load Q1

CDS overall heat load affected by TAOs on CV-04

In the spec, the design CDS heat load is 417W, while the tested CDS heat load is 424W~900 W affected by TAOs on CV-04 in CDS-el



ACCP supply stable helium: 8K, 2.2 bara

Heat load budget and measurements

Big picture for SCL operation

CDS-el spec: ESS-0011735

	Cold helium circuit		Thermal shield circuit	
	He supply line	VLP line	TS supply line	TS return line
CTL	10.3	31.8	5.5	450.8
CDL for High and Medium Beta linac sections	71.1	203.8	37.2	1831
Total:	81.4	235.6	42.7	2282
	317		2325	

CDS-sp spec: ESS-0017178

	Cold helium circuit		Thermal shield circuit	
	He supply line	VLP line	TS supply line	TS return line
CDL for the spoke linac including the valve boxes and end box	33.1 W	68.8 W	78.7 W	581 W
Total	102 W		660 W	

ACCP spec: ESS-0016596

Operation modes	2 K, W				4.5 K Liq., g/s	40-50 K, W
	Q1		Q2	Q1+Q2	F1	Q3
	Static	Dynamic	Static	Total	Static	Static
Nominal design	845	1007	627	2478	6.8	8551

Q1: Isothermal loads from CMs, Q2: Non-isothermal loads from CDS, F1: liquefaction rate for coupler cooling, Q3: Heat loads from thermal shield, Q1 and Q2 capacities in 4.5 K standby are at 4.5 K level.

Design CDS-el: 317W
Design CDS-sp: 102W

Design ACCP (x1.3x1.15): 627W

Performance tests ACCP: 880 W (*)
ESS-4001140
(*) at similar conditions with low number of CMs attached

Measured CDS loads: 424-934W(**)
(**) with moderate TAO dampening rather on the middle-lower end

Not great but no reason to panic yet:

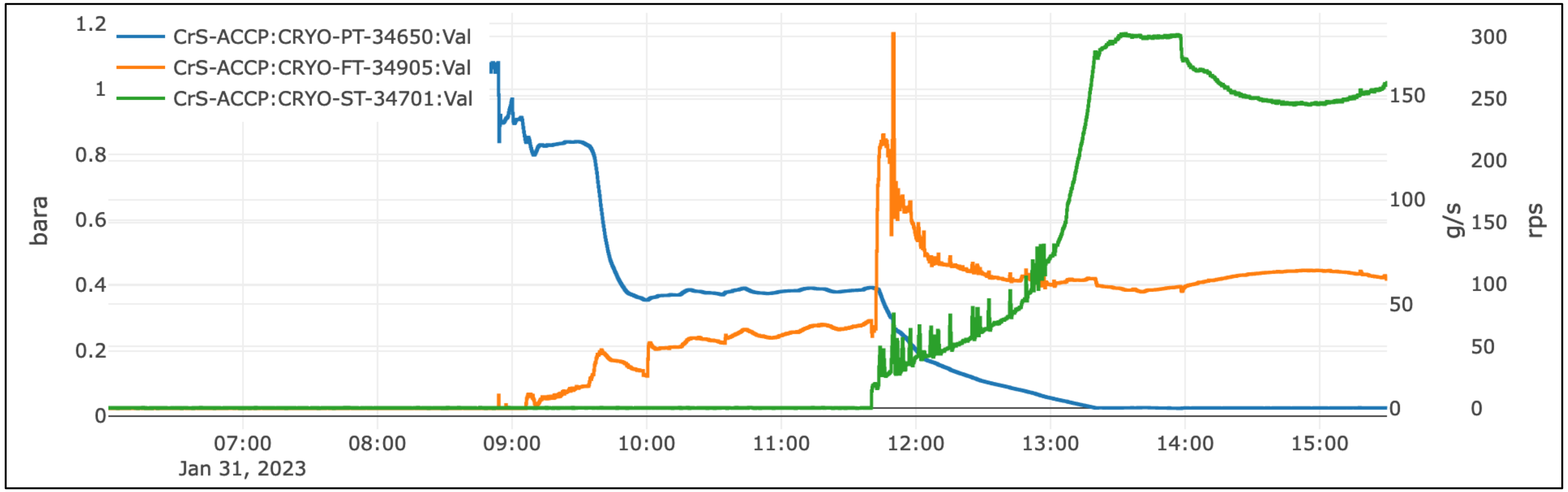
- CMs show so far good thermal performance, on average slightly below static and substantially below dynamic expected heat loads
- Much room for improvement on the CDS regarding TAO mitigation
- ACCP crank-up potential with existing parts: ~25%, also flexibility regarding load distribution

3

Cold compressors and endbox operation

Typical VLP line pump-down

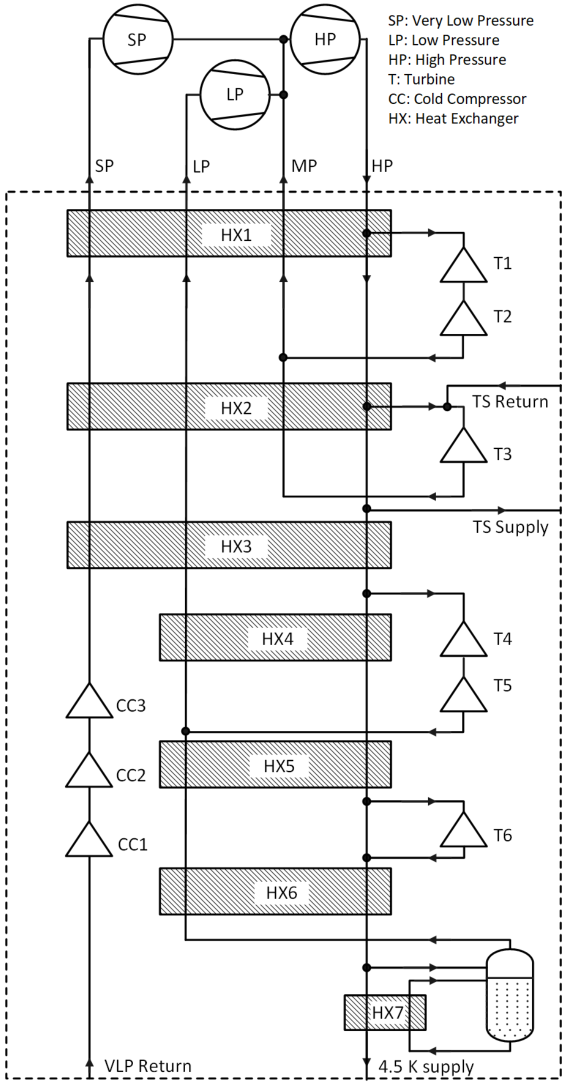
Verification of pump down capability with big volume



Pump down with warm SP compressor

Stabilisation / filling

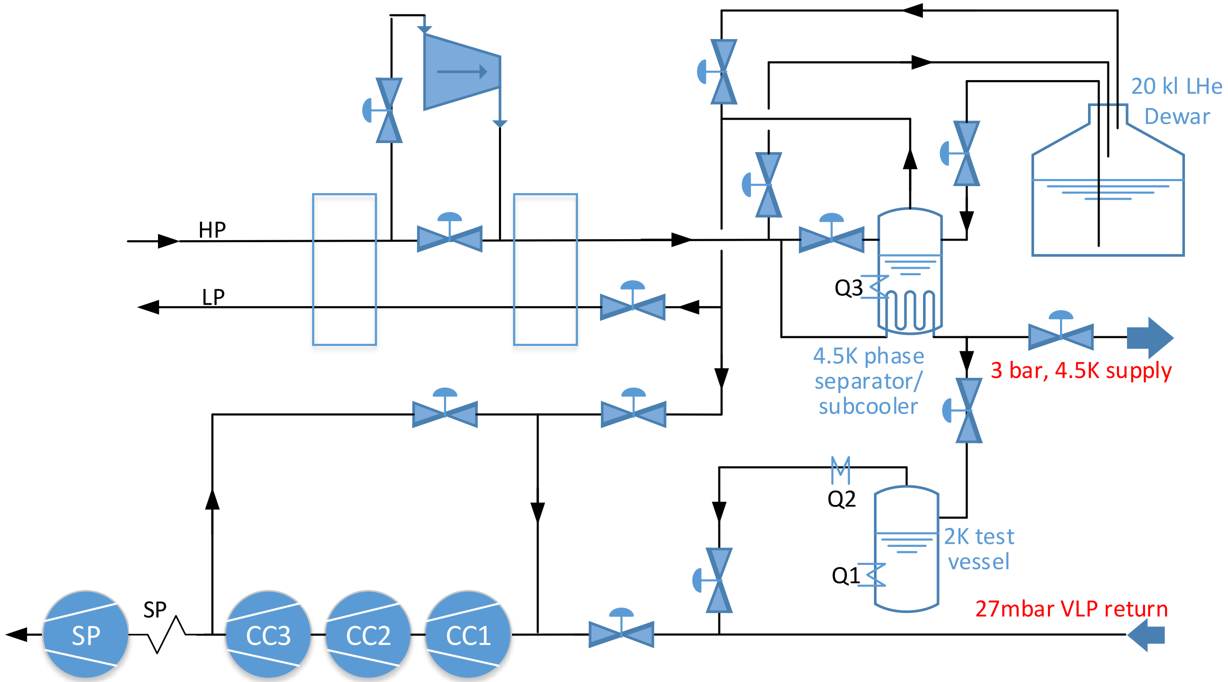
Pump down with CCs

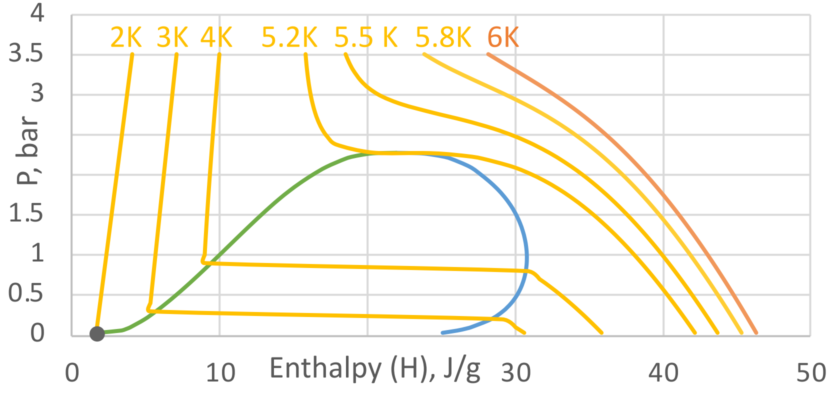


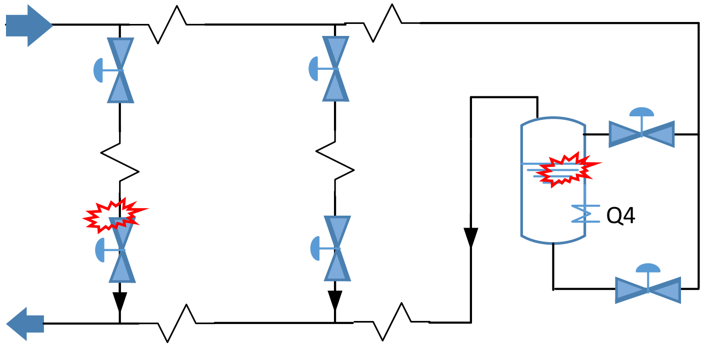
Several pump downs performed with ever decreasing pumping speed from 2.5 hrs down to 1.5 hrs depending on parallel endbox flow

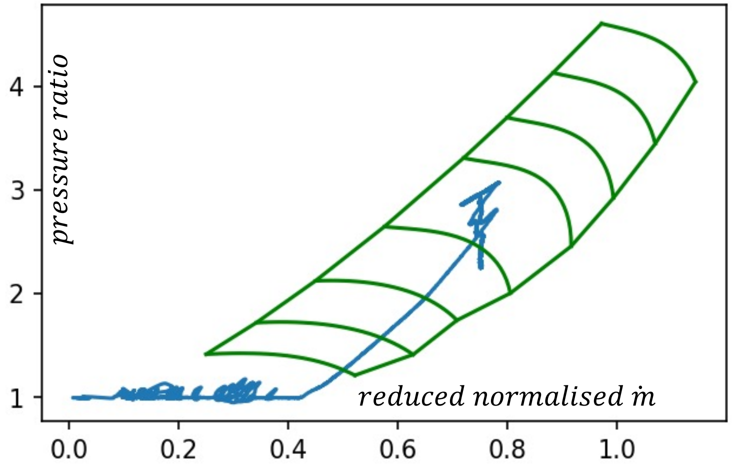
Several trips also, mostly after pump down during stabilisation phase, multiple reasons

Simplified process flow









CDS-el x 30 | CDS-sp x 13 | Endbox

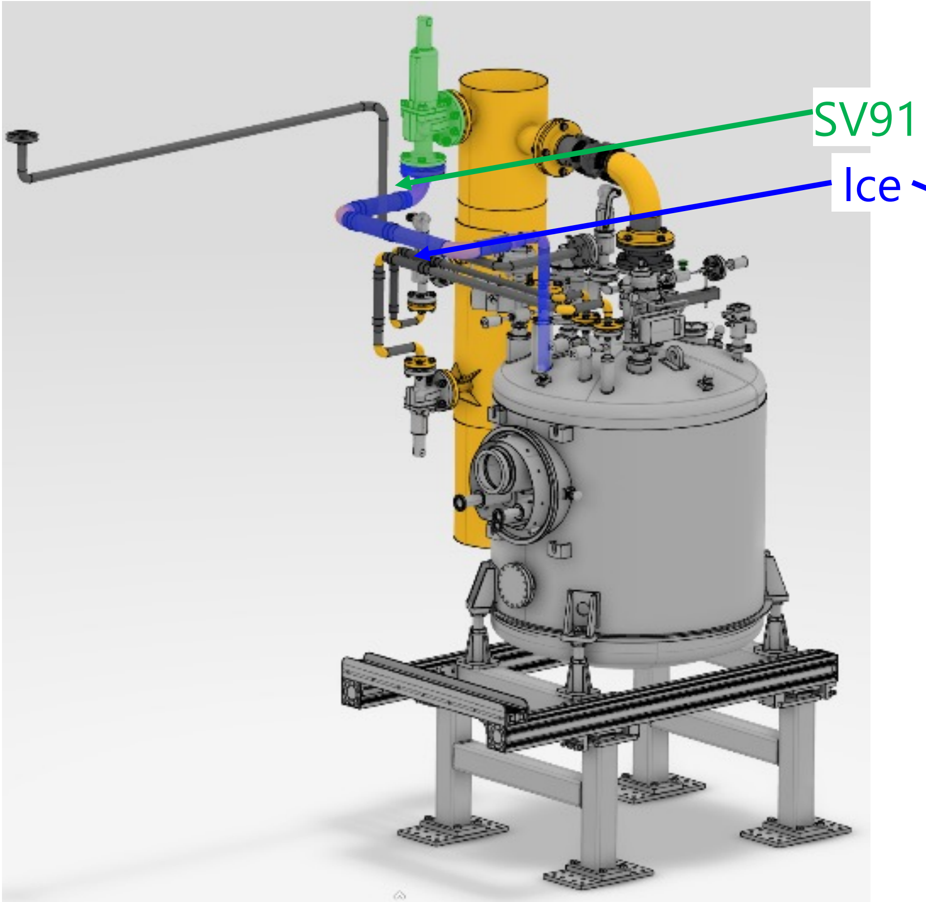
Supply flow: 3 bar, 6K, 65…97 g/s

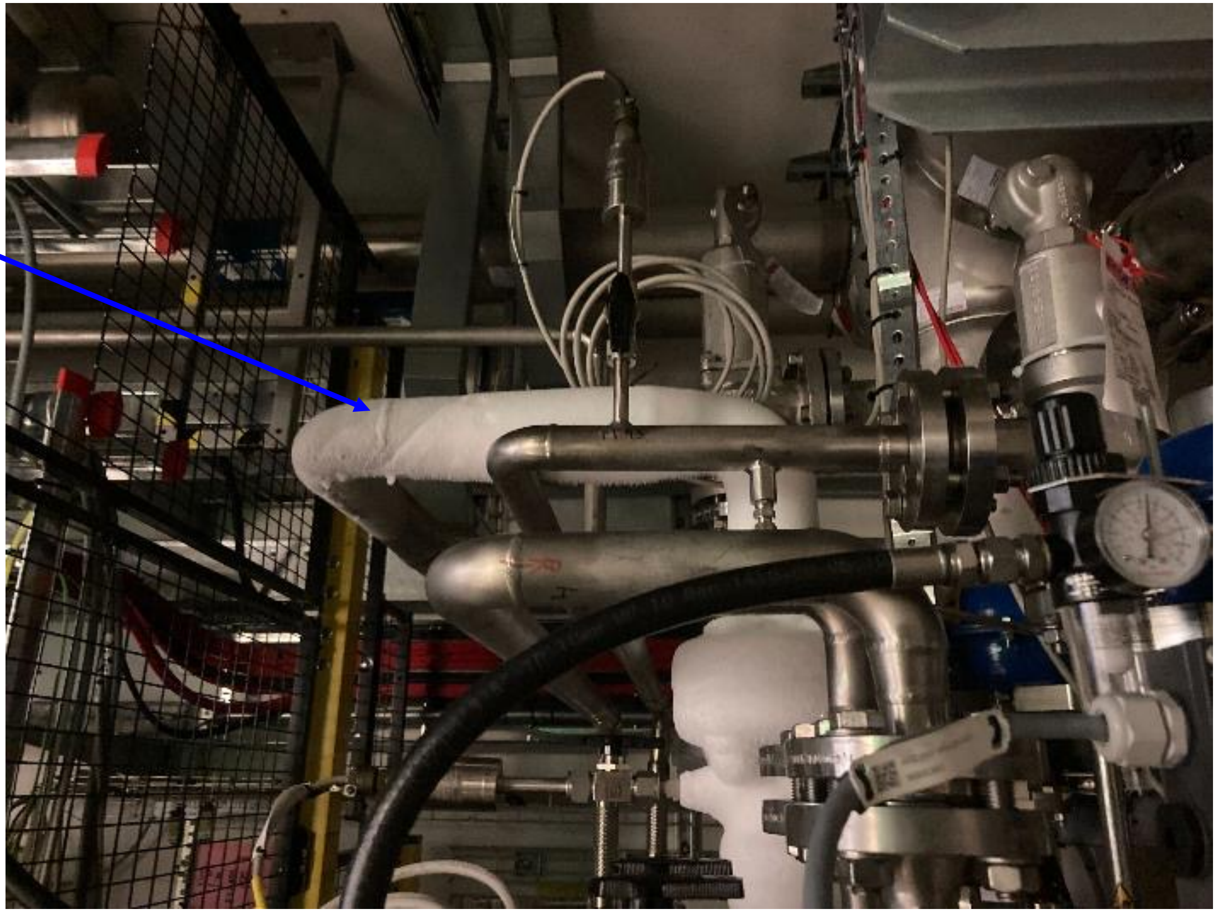
Dysfunctional internal CC bypass controls at elevated temperatures.

Due to violent TAO at Endbox in colder conditions no attempt to operate CCs with liquid in endbox.

TAO on the endbox

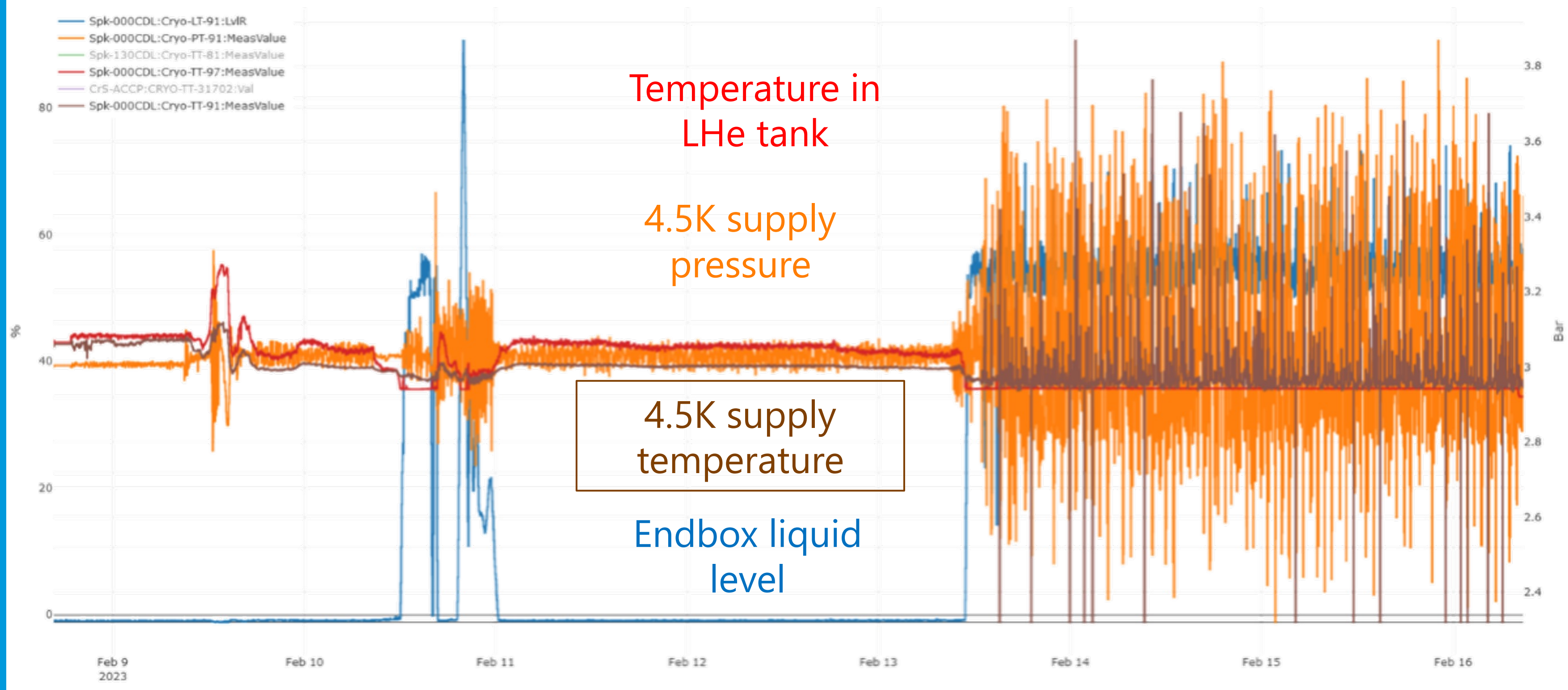
Inlet line to SV for 4.5K supply

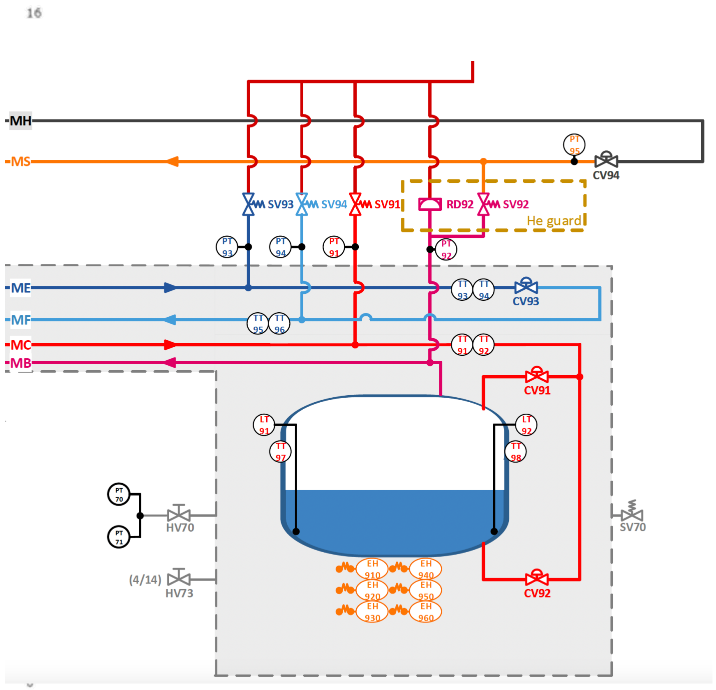




TAO on the endbox

Very specific operation conditions





Main frequency ~0.4 Hz → could fit to an acoustic wave through the whole supply line (450 m long)

Large heat transport in the vertical chimney where the temperature gradient is present

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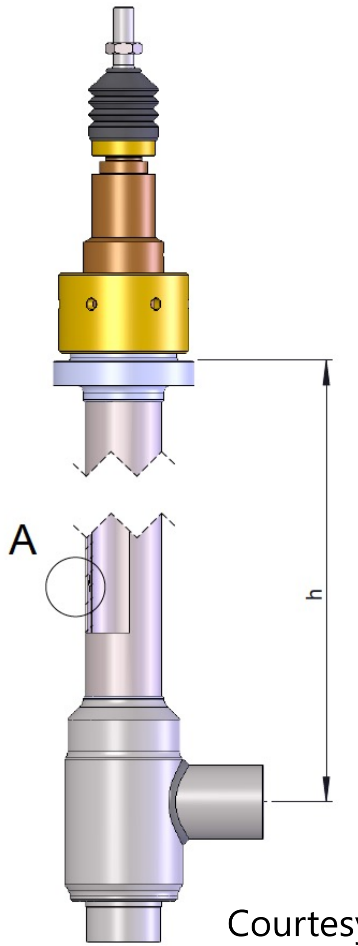
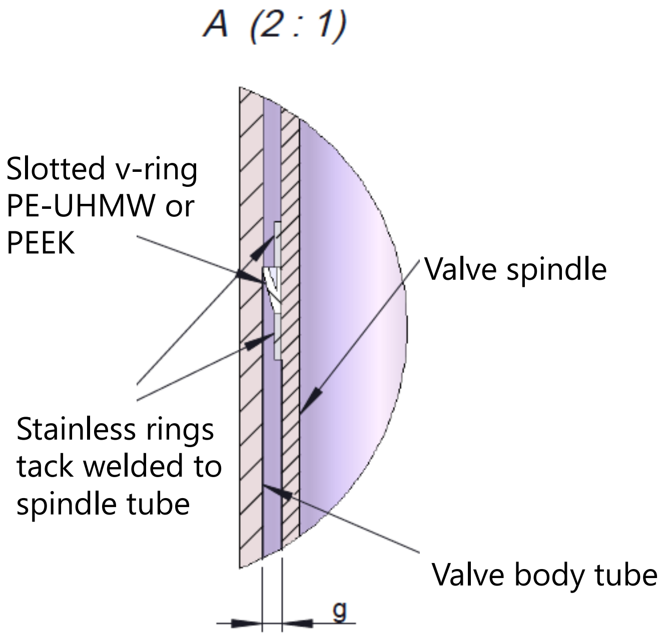
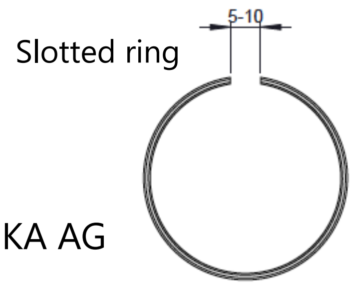
Repair activities and summary

TAO on 30 x CV04

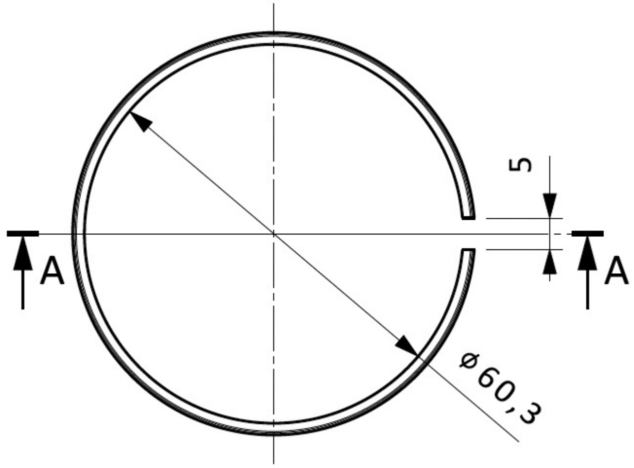
Eliminating TAO by using wipers



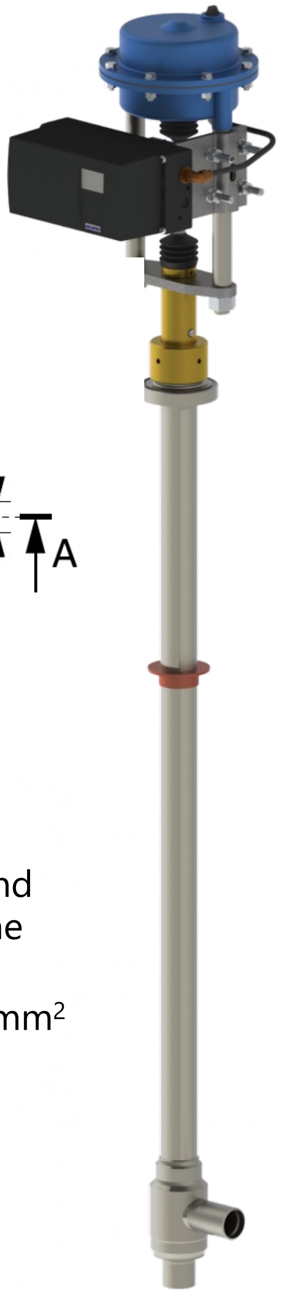




Courtesy of WEKA AG



Annual gap between valve body and insert (dimension g) is 2 mm for the DN50 valves
→ Residual cross section of ~500 mm^2 (equivalent DN20)



TAO on 30 x CV04

Finding the right wipers

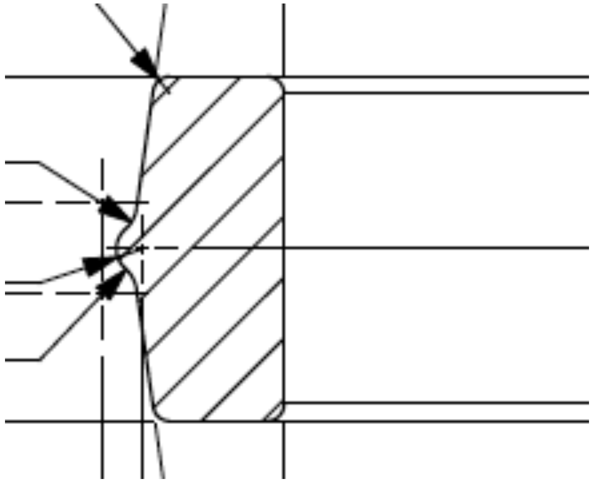
Interesting papers from FNAL (US), NSRRC (Taiwan) and others

PAPER · **OPEN ACCESS**

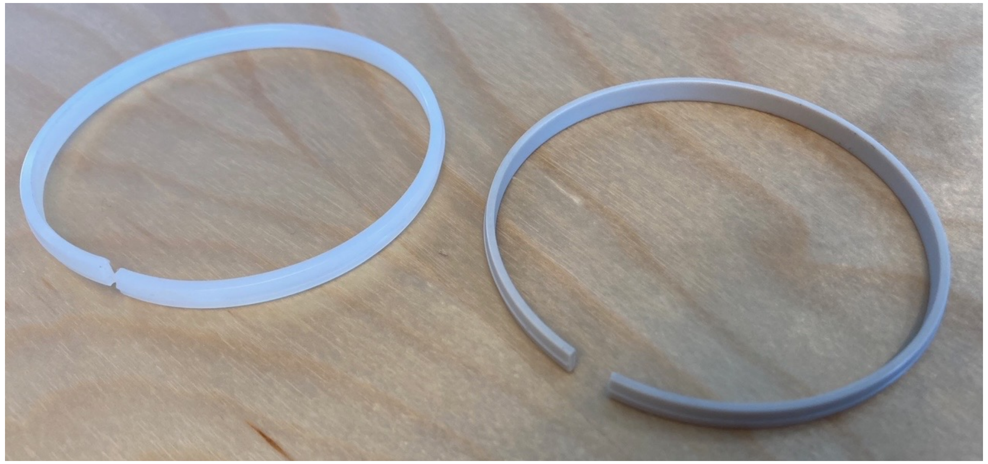
Effects of thermal acoustic oscillations on LCLS-II cryomodule testing

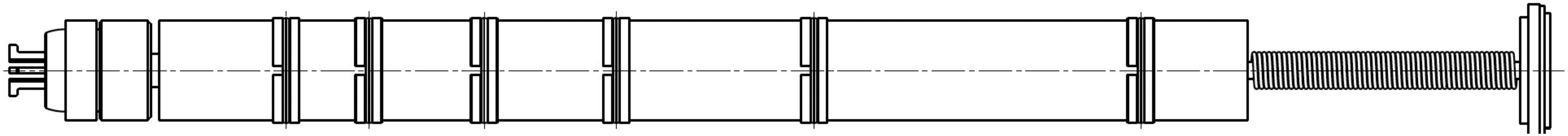
To cite this article: B J Hansen *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **278** 012188

This ring design did not work out very well due inflexibility and tolerances



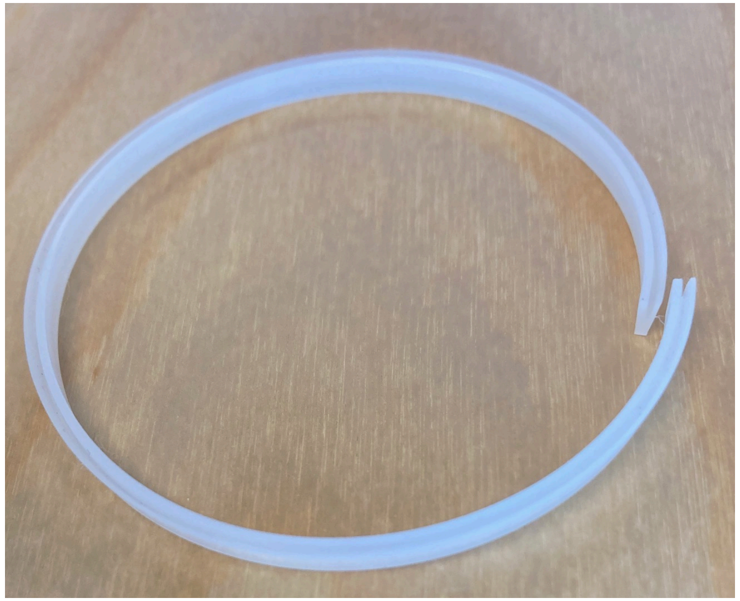
Slotted ring PE-UHMW or PEEK





TAO on 30 x CV04

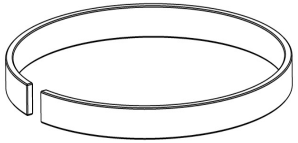
Finding the right wipers



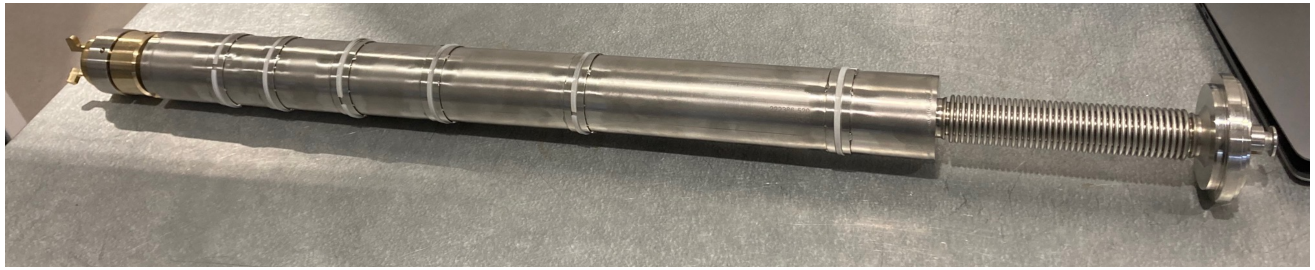
V-ring design by WEKA,

Works very good on tested valve bodies

First batch of dismounted valve stems



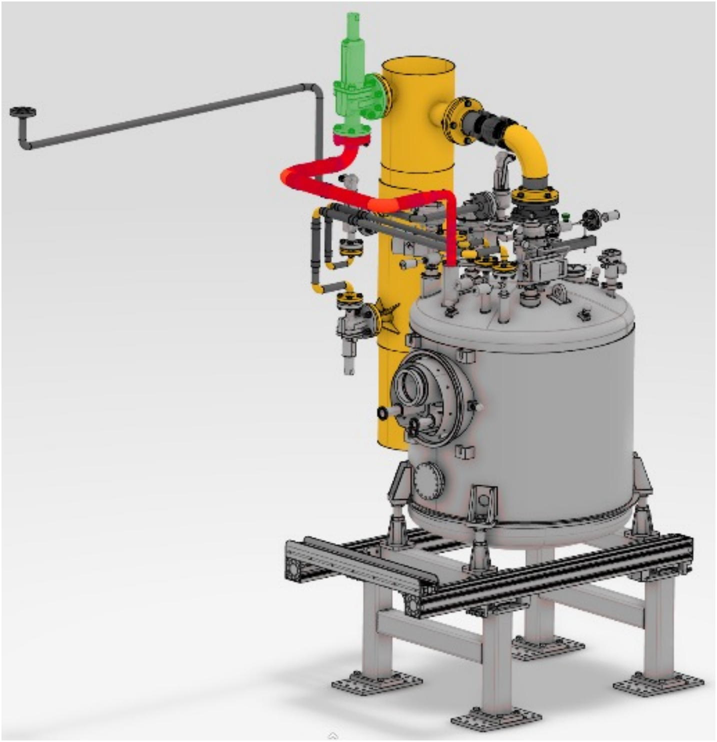
Biggest job: 12 very thin stainless rings to be welded on the stem

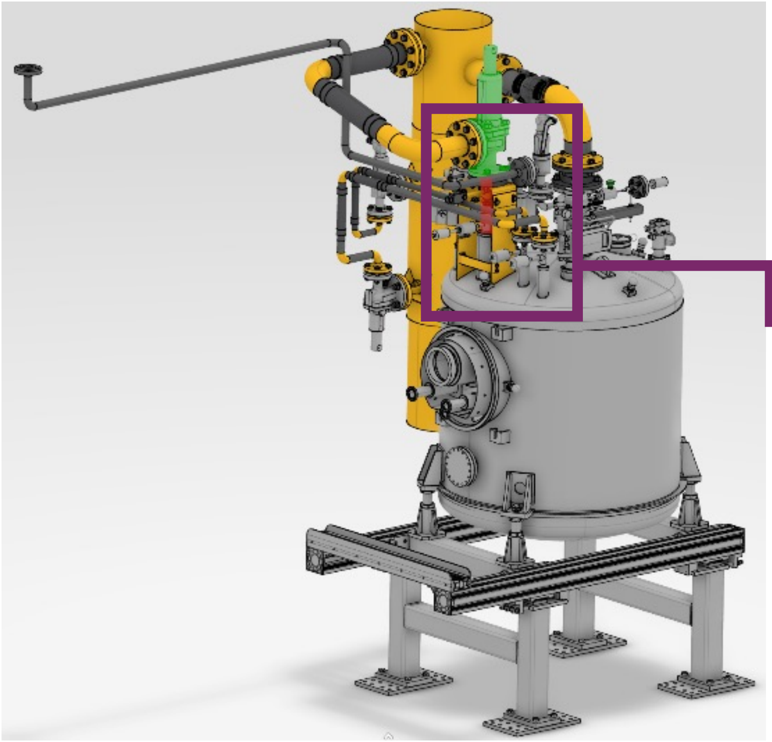


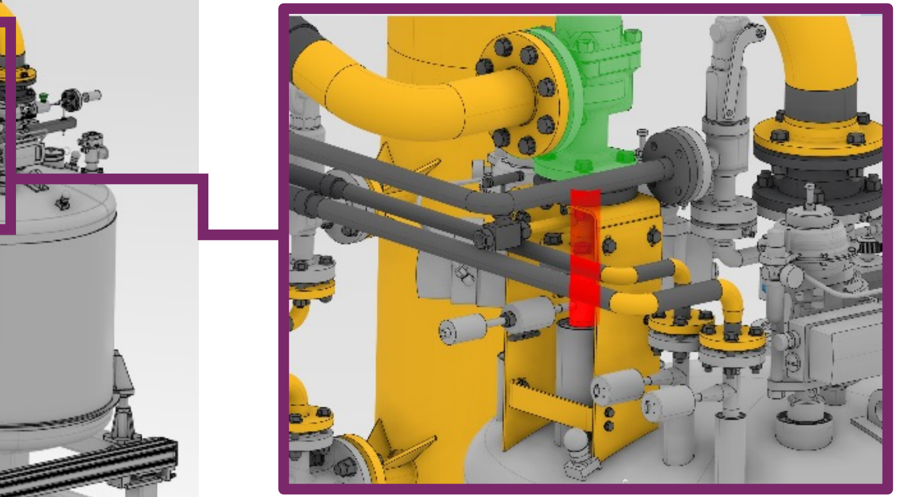
Wipers mounted carefully piece by piece while sliding the insert into the valve body

Eliminating TAO on the endbox (1)

Shorten inlet line of SV

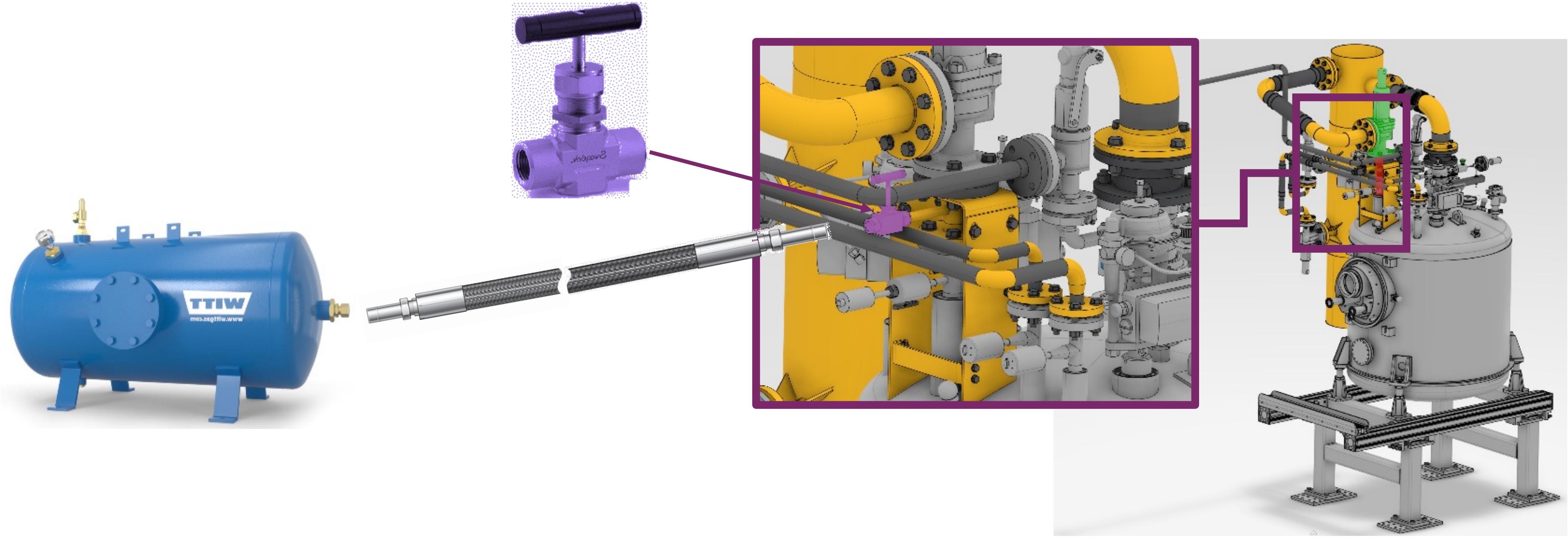






Eliminating TAO on the endbox (2)

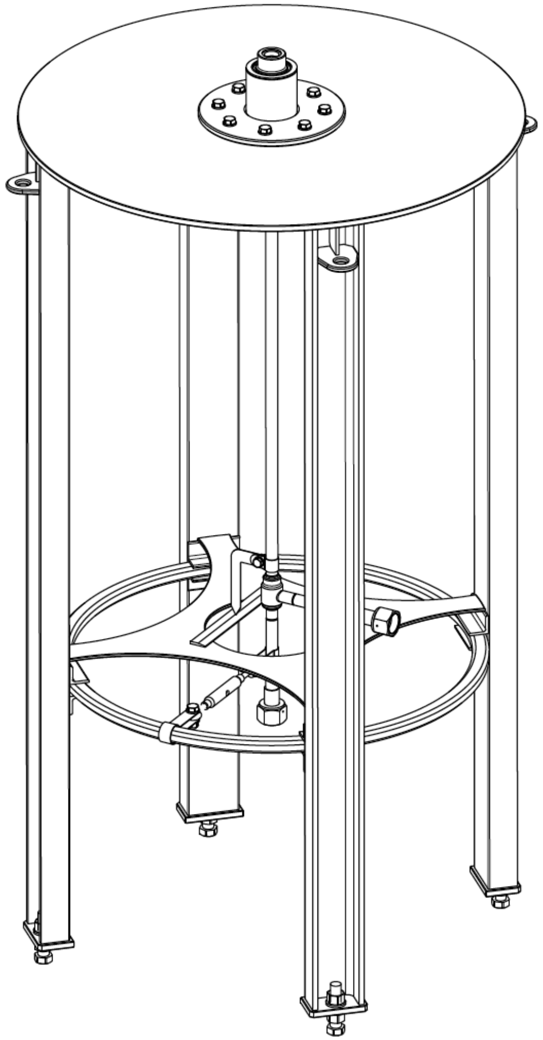
Adding RLC system to detune / damp the acoustic resonance



Credit: Mathieu Pierens, IJC Lab

Control valve tightness test rig

Cryo lab setup in order to find leak conditions



- testing deformations of a spare CV61 valve body
- Testing different actuator configurations
- Testing own produced seat seals
- Verifying other designs of inserts, e.g. with a self-adjustable plug and/or a less rigid spindle.

Summary

Conclusions of the first cooldown

We cooled down the system, conducted the tests and warmed up all according the pre-agreed plan although we had substantial setbacks. The test results are mixed.

Main Objective	Result	
Cooldown and show mechanical integrity	Done.	✅
Functional testing of controls and instrumentation	Mostly done, TTs around 2K HX in CDS-sp still to be characterised. Some punch points left.	✅
Heat load verification	Partially done. Testing effected by TAO in CDS-el CV04s but reason to believe heat loads are in budget once the TAO are mitigated.	😕
Cold compressor operation incl turndown	Pump down and full load was verified. Turndown not possible due to system test limitations and TAO in endbox.	😕
Endbox LHe gauges and heaters verification	Done.	✅

Status and next steps

Investigations, repairs, preparations for 2nd cooldown

Following the CDS testing **pilot CM installation started**, on **SPK 110** and **MBL020**.

In parallel the CDS modification and repair is underway with priority on:

- Repair TAO on CDS-el CV04
- Repair TAO on endbox
- Repair leaky CDS-el SV02
- Control logic adjustments on the ACCP

Furthermore the root cause of CDS-el CV61 misalignment and high leak rates through these valves is investigated and eventually repaired.

2nd Cooldown shall be done with filled LHe Dewar to facilitate CM filling and cold compressor turndown operation.

Thank you for your attention.

Finish presentation