Overview of the Helium Collector

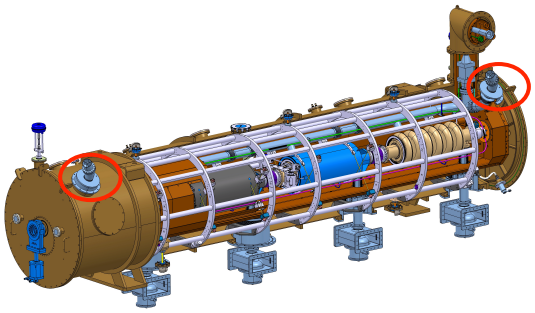
Elliptical Cryomodules Critical Design Review – April 3,4

EUROPEAN SPALLATION SOURCE

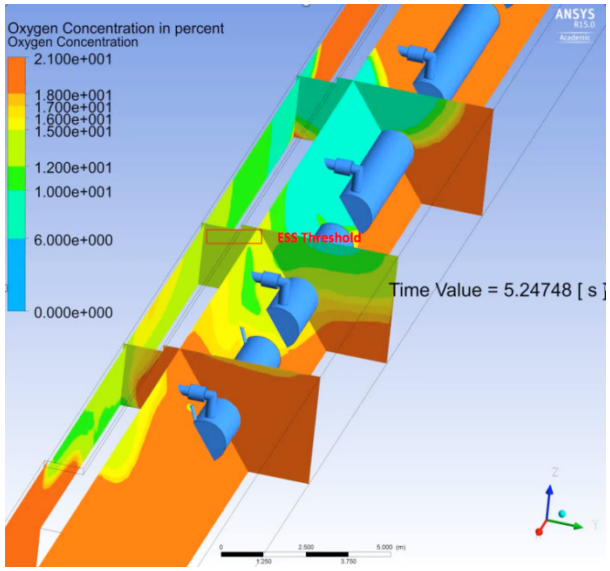
Helium collector project team
J.Moberg, J.Fydrych, E.Lundh, D.Phan & J.Weisend

Main motivation

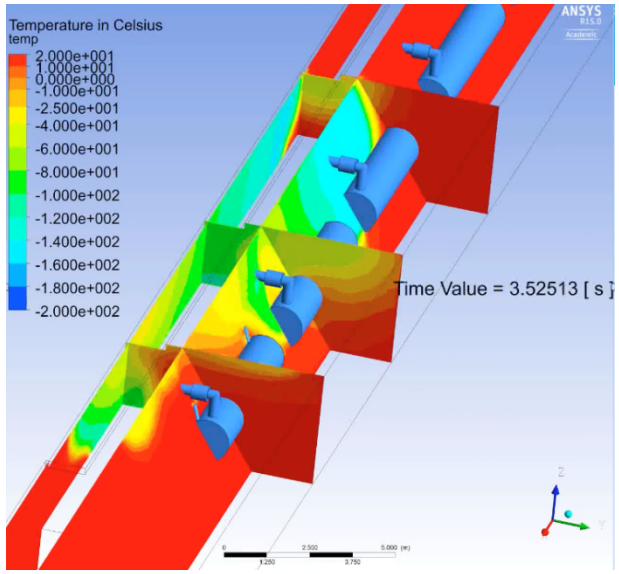
In Q4 2015, the ESS AD Safety Group with the help of the EIS Division investigated possible cold helium propagations in the tunnel for several credible failure scenarios.



Loss of beam vacuum



Lowest attainable O2 concentration = 6%



Lowest attainable temperature = -135°C

A collection header for evacuation of cold helium vapour may reduce or eliminate Oxygen Deficiency Hazard (ODH) and personnel exposure to cold burns

Source: D.Phan and E.Lundh:**ESS ODH concept and on-going safety study** presented during "Cryogenic Safety Workshop at ESS" on 2016.02.10

History

ESS Cryogenic Safety Workshop – Feb. 2016

"Technical solutions to vent the helium coming out from the burst disks of the 2K helium vessel to a safe place should be investigated. Facilities like XFEL, Fermilab and ORNL only vent the vacuum vessel of cryogenic systems in the tunnel."

ESS Cryomodules Safety Review – June 2016

"Integrating in the tunnel a helium collector in order to discharge helium outside the tunnel is a very interesting solution in order to cope with the risk of ODH and cold burns to personnel in the vicinity of the cryomodules. The committee supports the continuation of this work with high priority, as well as the evaluation of the impact of this system on the cryomodule design and integration aspects in the tunnel. "

Main function and design constraints

Function

The helium collector is designed to be able to collect the helium released by the burst disks of the 2 K helium vessel of the cryomodules and vent it outside of the tunnel in order to prevent exposure of the personnel to helium releases during access to the tunnel (Beam OFF).

Design constraints

The helium collector shall be designed in such a way that the impact on the cryomodules design and operation (both elliptical and spoke) is very limited:

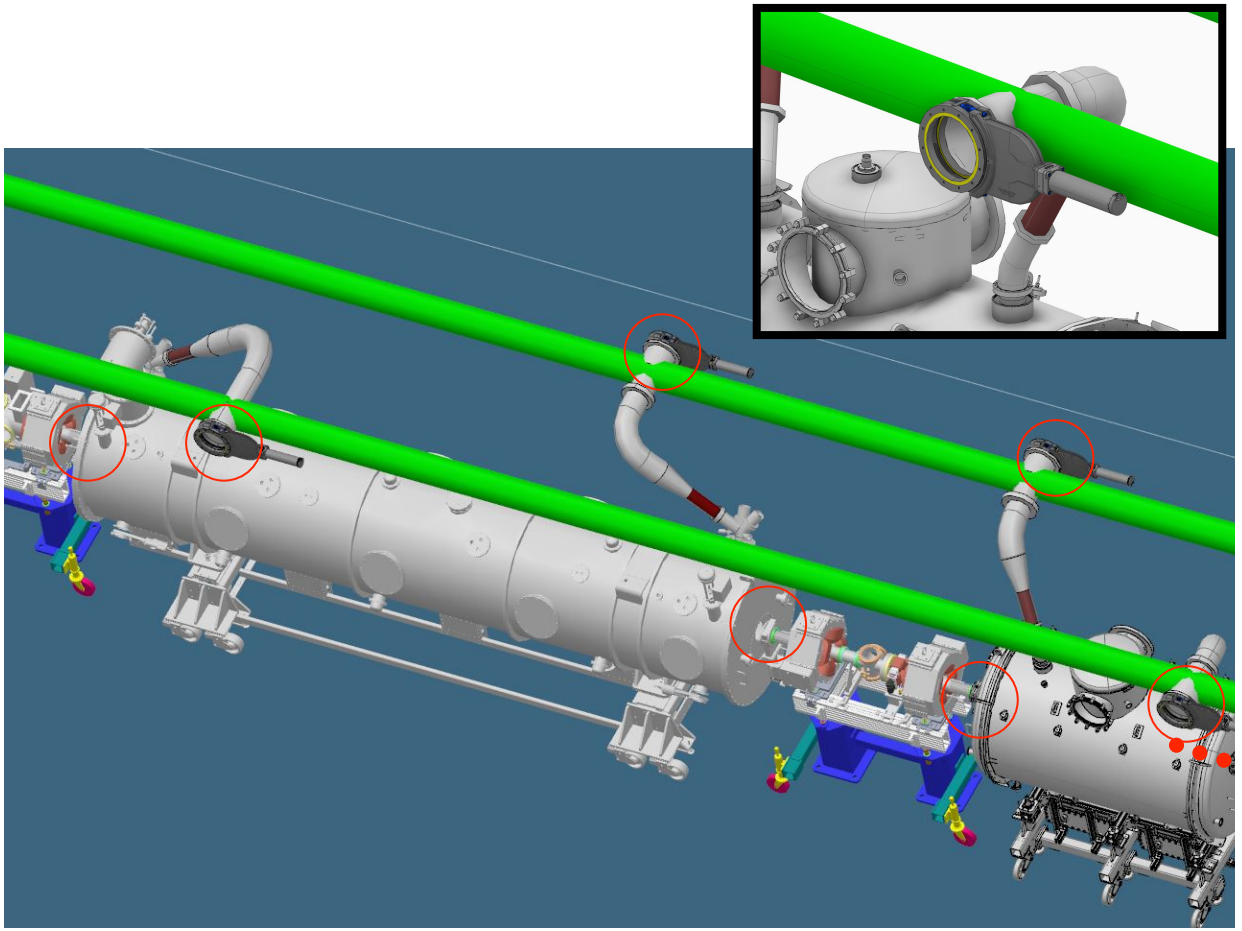
- Maximum allowable pressure of 1.9 bara at the outlet of the cryomodules' burst disks.
- The helium collector shall "behave" as if there was no collector during operation (Beam ON) to limit back-pressure effects.
- Limit as much as possible the pressure drops in the connection line between the burst disks and the collector.

Main function and design constraints

BEAM ON

Access	No personnel allowed in the tunnel
CM gate valves position	Open
Collector gate valves position	Open
Helium collector "mode"	Inactive
Worst case scenario	Release of helium from 6 elliptical CM* caused by accidental beam loss

This is a **very low probable event** considering the Machine Protection System (MPS) in place



Acknowledgement: J.Moberg & C-J.Hårdh

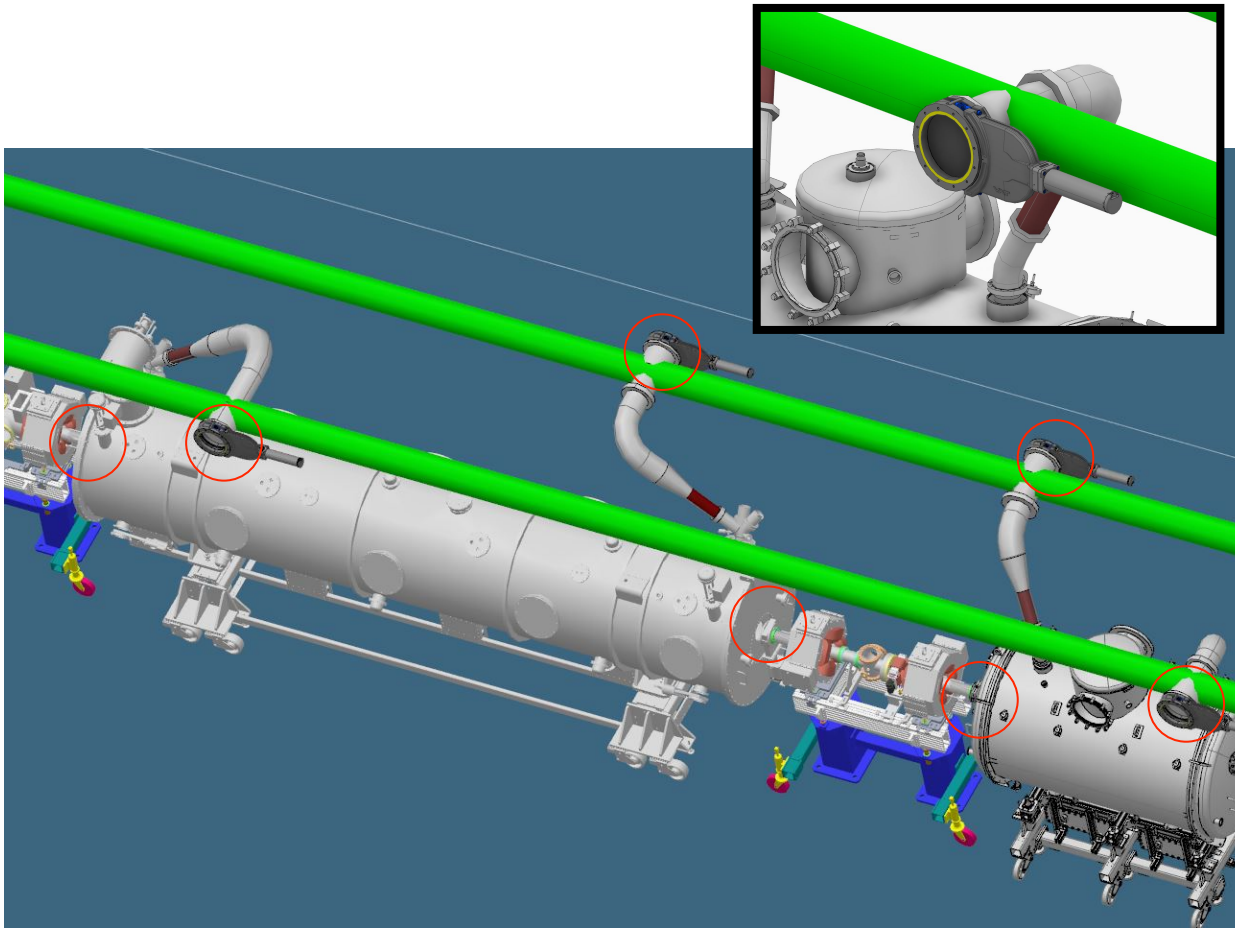
*The loss of 6 High-β (or 8 Spoke) was estimated based on an average air propagation speed of 3 $m.s^{-1}$ in case of an air inleak in the beam vacuum assuming that the gate valves would close in 4 seconds. As a result, air would propagate along the beam pipe (12 m on each direction) and thus affecting a total of 4 High-β (or 6 Spoke). A safety margin of an extra cryomodule on each side has been added to this number.

Source: A.Dalesandro & R.Dhuley, **Results from sudden loss of vacuum on scaled superconducting radio frequency cryomodule experiment**

Main function and design constraints

BEAM OFF

Access	Personnel allowed in the tunnel
CM gate valves position	Closed
Collector gate valves position	Closed
Helium collector "mode"	Active
Worst case scenario	Release of helium from 1 CM*

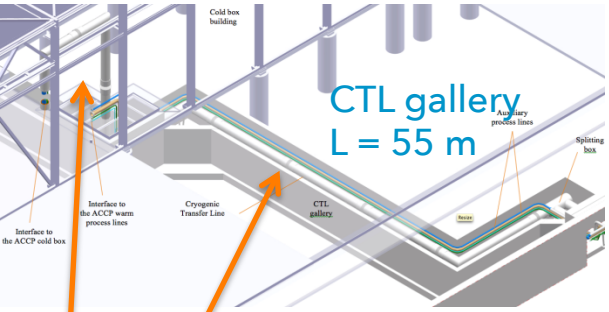


Acknowledgement: J.Moberg & C-J.Hårdh

*This assumption was made based on the fact that the gate valves of the cryomodules are closed, thus preventing the helium release from several cryomodules at the same time

Routing of the collector

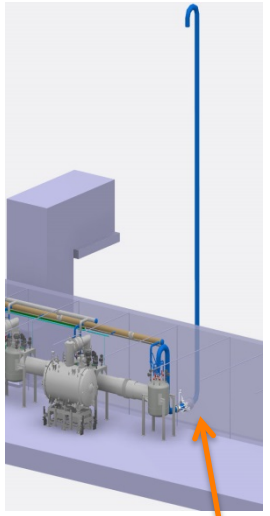
Cold box room
vent line



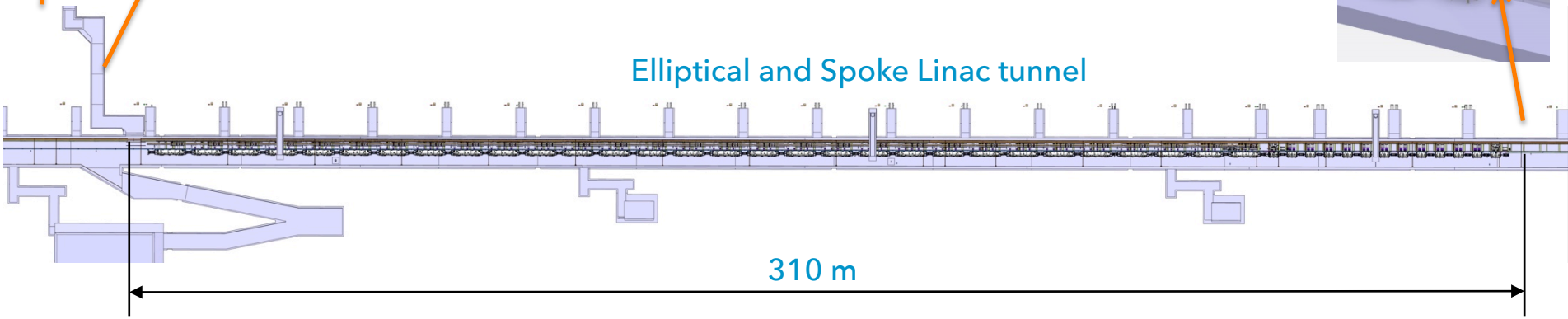
CTL gallery
L = 55 m

Total length of the collector < 400 m

CDS vent line
L = 12 m, DN400

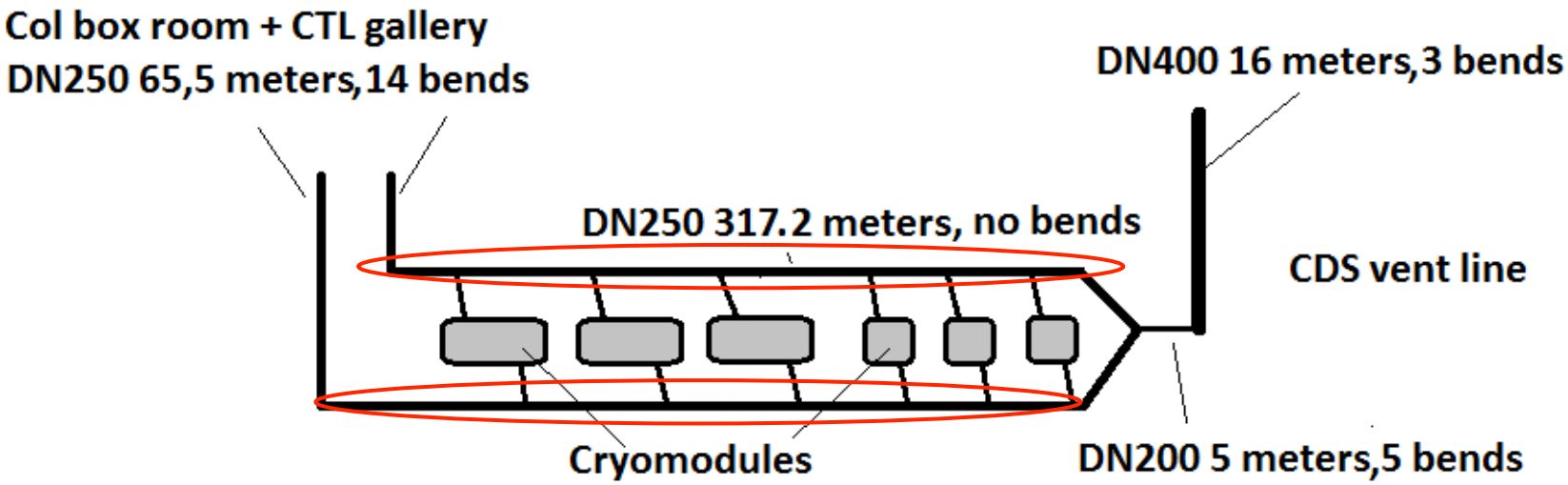


Elliptical and Spoke Linac tunnel



Acknowledgement: J.Fydrych

Collector concept – double pipes

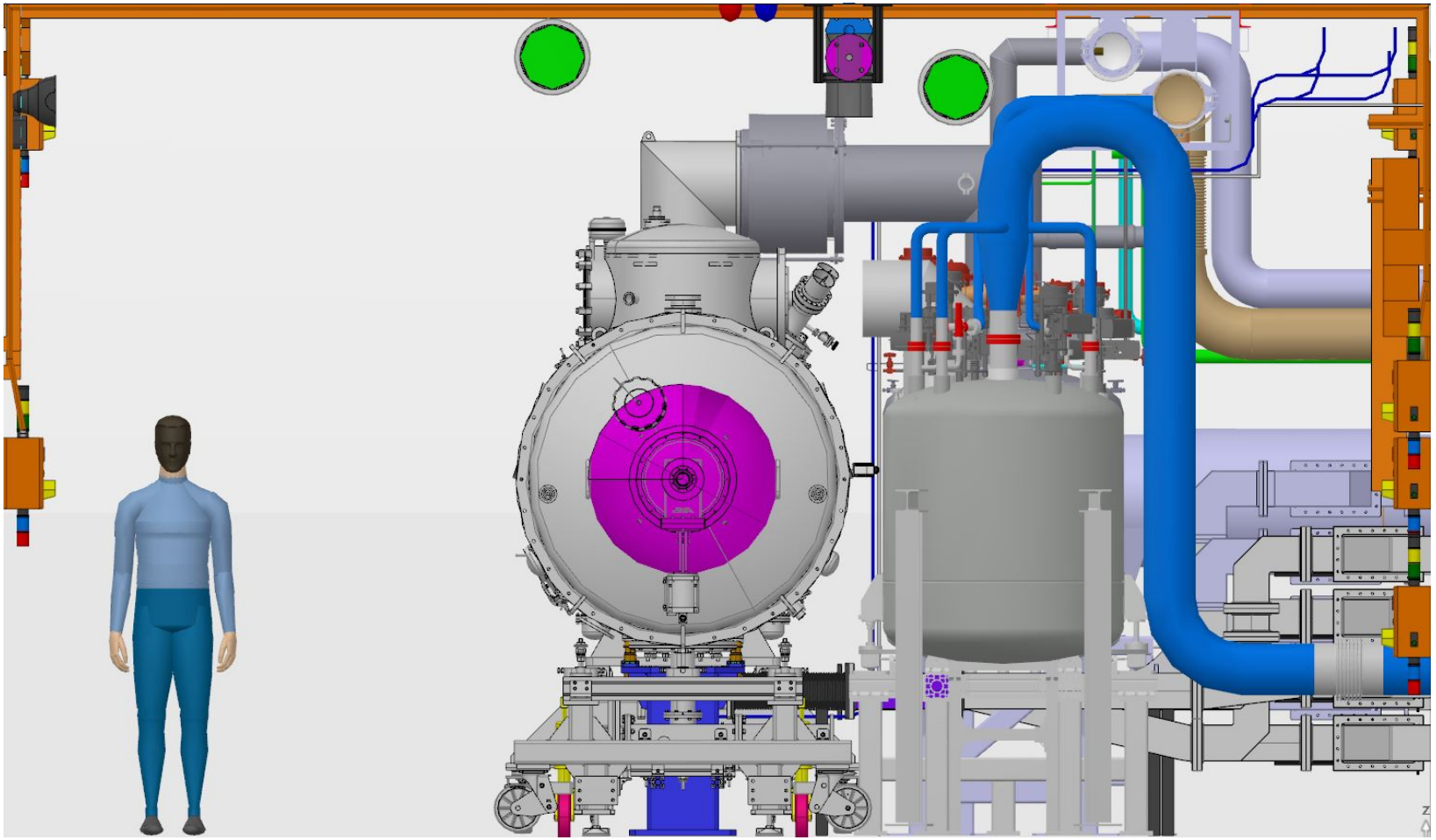


Main motivations:

1. Reduce back-pressure effects from one release point to adjacent burst disks
2. Cope with the mechanical integration constraints of the accelerator tunnel

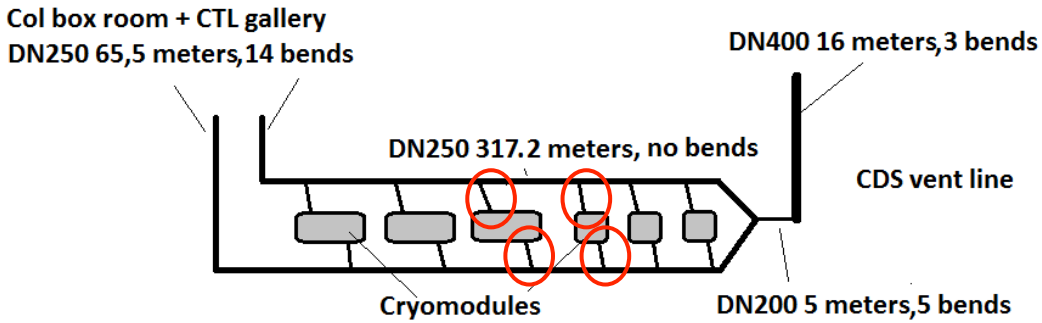
Acknowledgement: J.Moberg

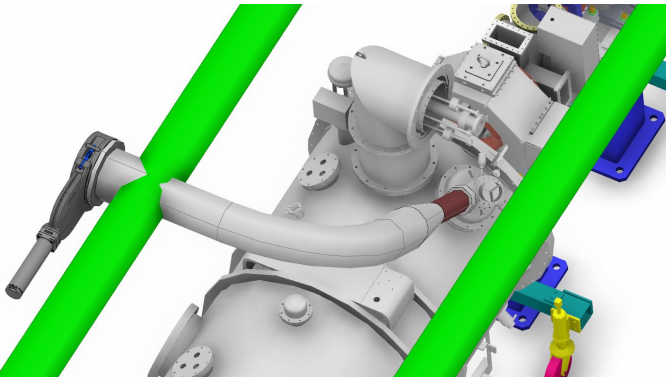
Cross-section of the accelerator tunnel

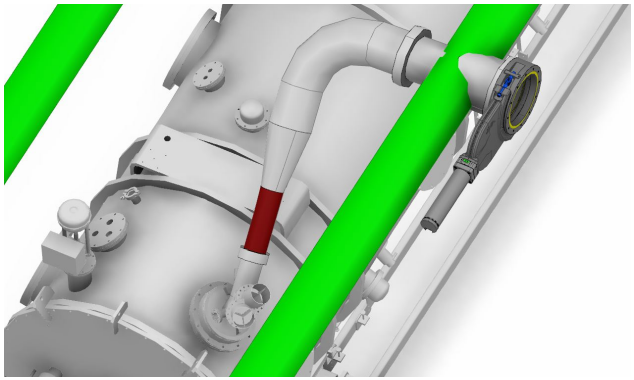


Acknowledgement: J.Moberg & C-J.Hårdh

Collector concept – connection lines



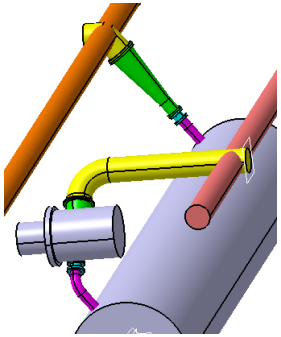




Elliptical cryomodules

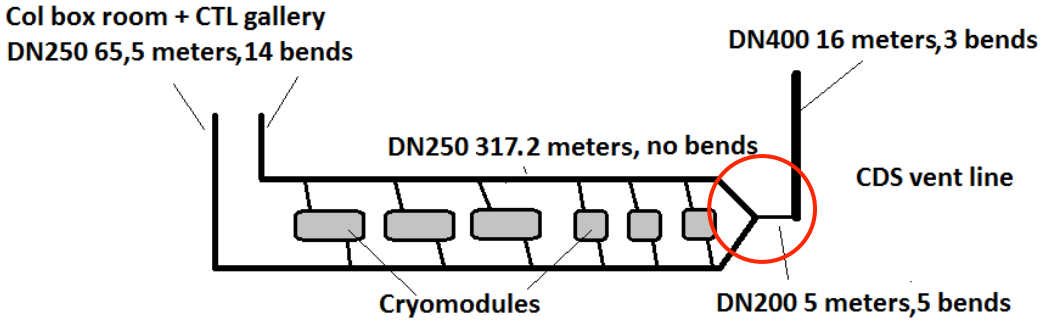
Spoke cryomodule

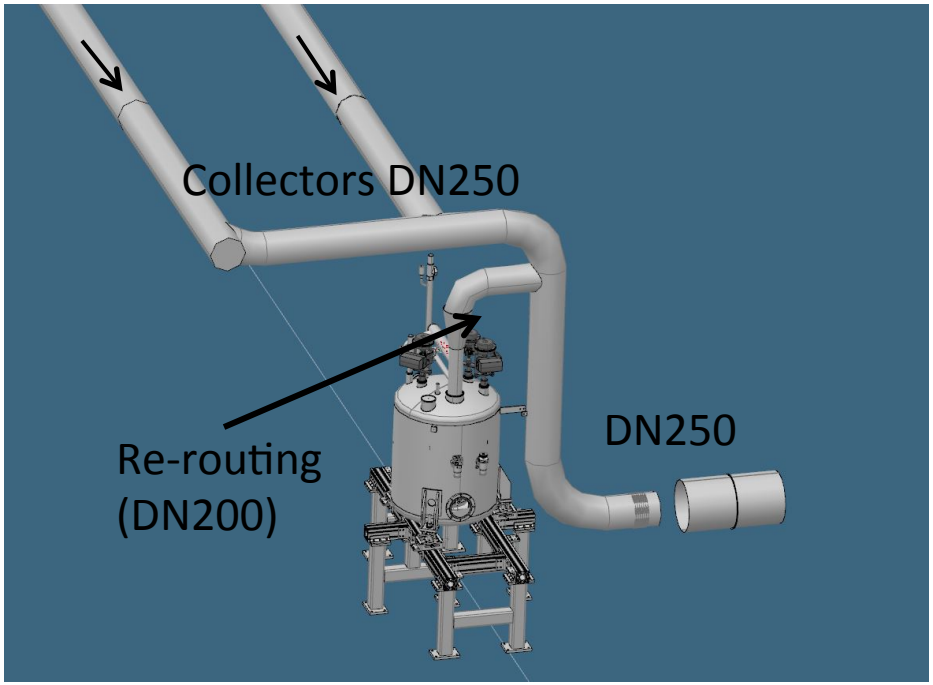
Design proposal for the Elliptical CM submitted by G.Olivier (IPNO) on March 30th to be evaluated by ESS in the coming days



Acknowledgement: J.Moberg

Collector concept – connection to the CDS vent line





Acknowledgement: J.Moberg

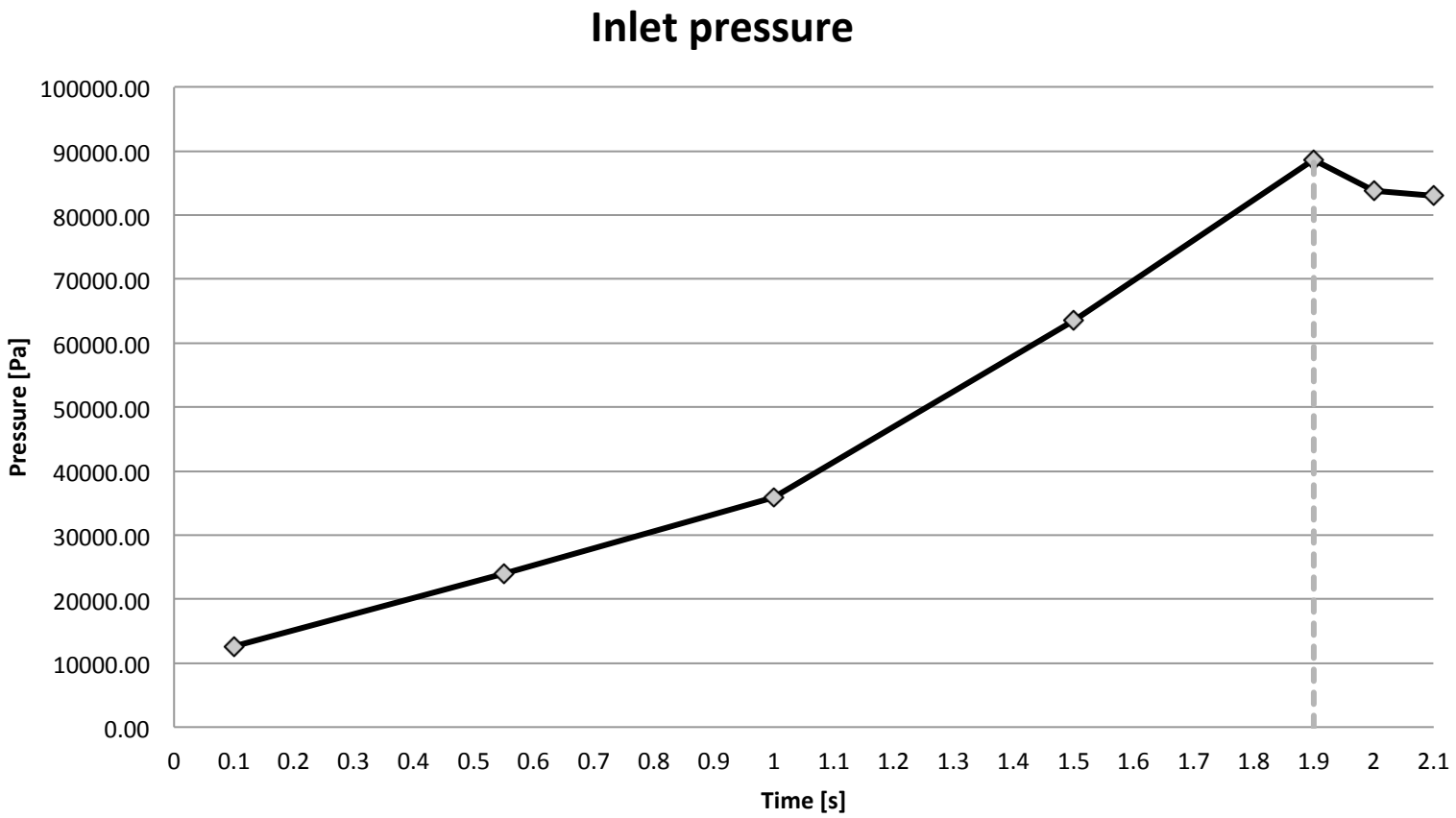
Pressure calculations

Assumptions

- Type of helium collector: **two-pipes type** –> one pipe connected to every 2nd burst disk
- Diameter of the helium collector: **2 x DN 250**
- Type of cryomodules: **Elliptical**
- Distance considered between two burst disks of the Elliptical section: 8.4 m
- Temperature at the outlet of the burst disk: **5.06 K** (corresponding to the saturation pressure of the fluid)
- Mass flow rate of one Elliptical cryomodule: **7.2 kg/s per burst disk**
- Duration of the release: **1.9 seconds**
- Maximum allowable pressure in the collector: **1.9 bar(a)**

Acknowledgement: J.Moberg

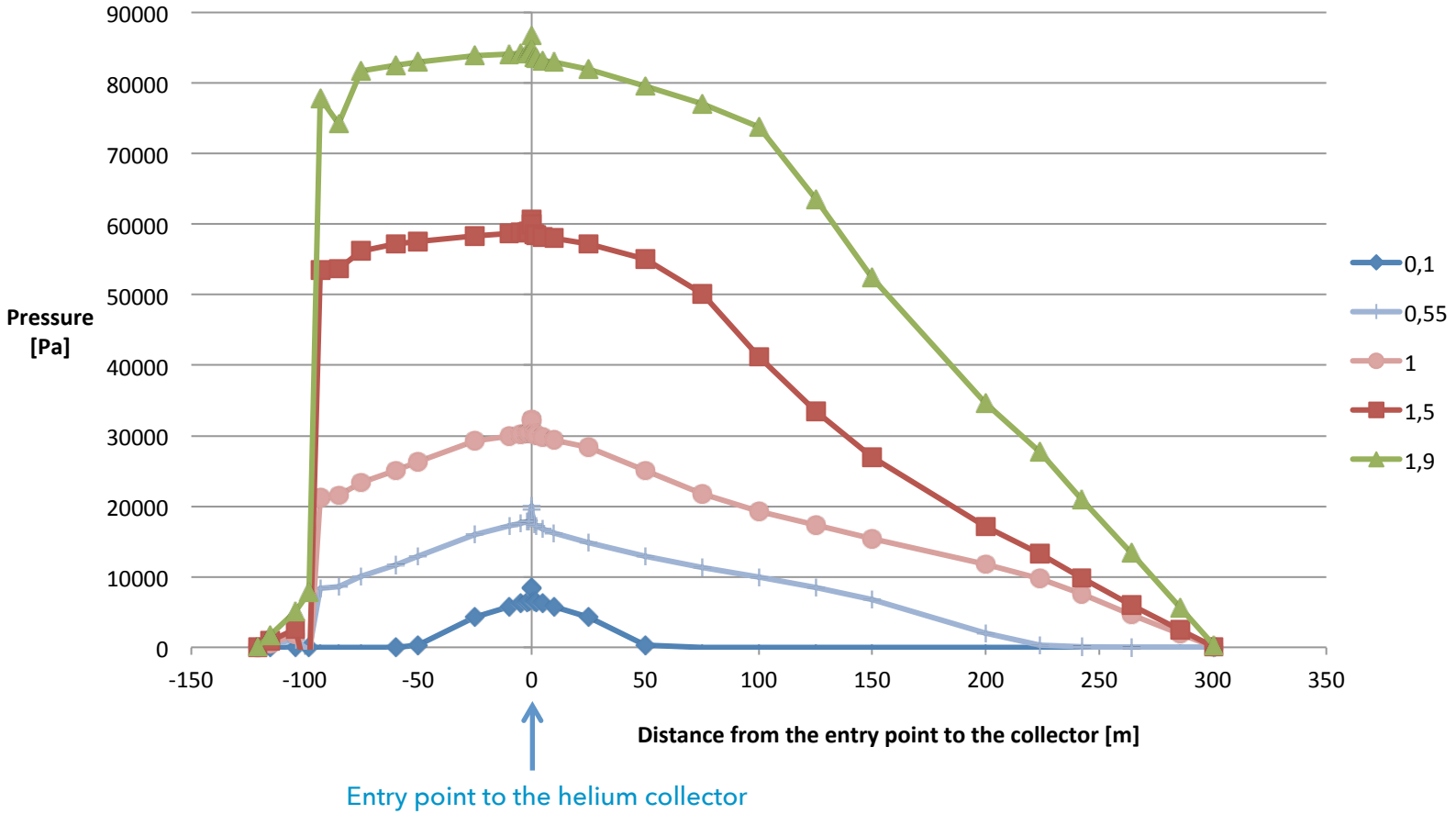
Pressure at the discharging burst disk*



*Calculations were made assuming a 2m long DN150 straight pipe between the helium collector and the burst disks of the cryomodules

Acknowledgement: J.Moberg

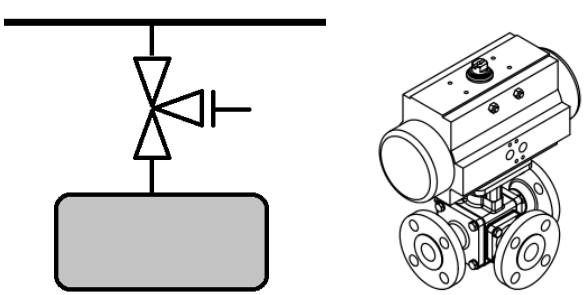
Pressure within the helium collector



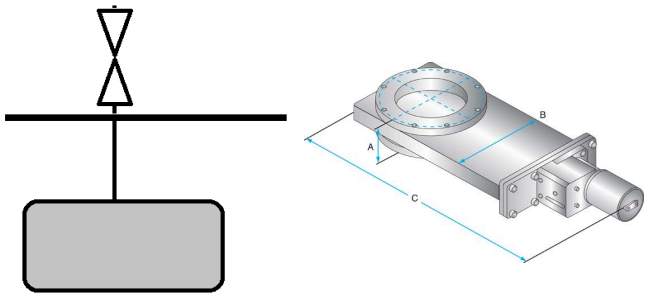
Acknowledgement: J.Moberg

Collector openings– Engineering solutions

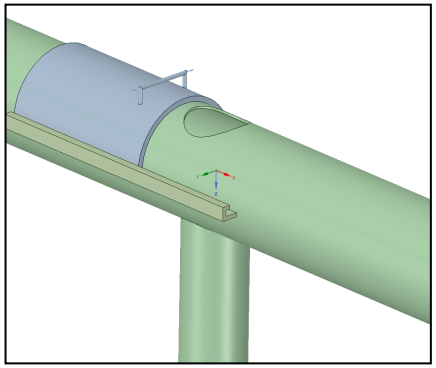
5 different options investigated but only 2 were retained



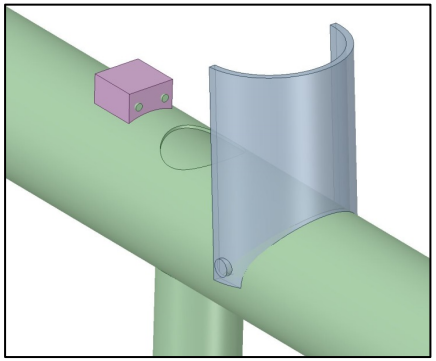
Option n°1: 3-way T port valve



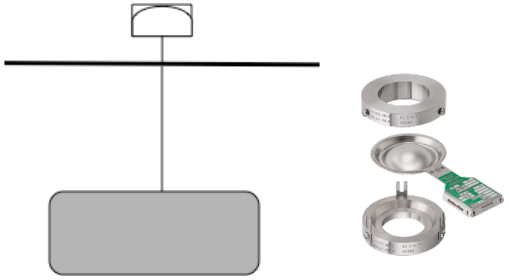
Option n°2: Gate valve



Option n°3: Slider valve



Option n°4: Flap valve



Option n°5: Burst disk

Acknowledgement: J.Moberg

Collector openings – Gate valves

Acknowledgement: J.Fydrych

Component	Unit price	Quantity	Total price
Vacuum valves (DN250)	4100 EUR	90 pcs	369,000.- EUR
Valve Controls	400 EUR	90 pcs	36,000.- EUR
DN250 pipe	80 EUR	800 m	64,000.- EUR
Supports	300 EUR	200 pcs	60,000.- EUR
Hoses DN100	300 EUR	86 pcs	26,800.- EUR
Bellows DN250	600 EUR	50 pcs	30,000.- EUR
Installation	200 EUR	800 m	160,000.- EUR
			744,800.- EUR

+

- Remotely controlled
- Off-the-shelf product
- Efficient perforation of the collector during operation (Beam ON)

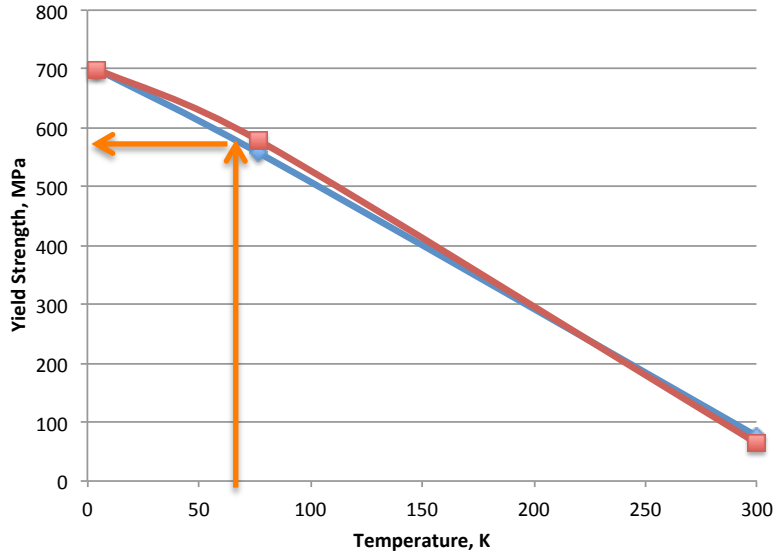
-

- Poor accessibility of the gate valves
- Cost
- Complex maintainability (90 valves + 180 switches)
- Failure probability?*

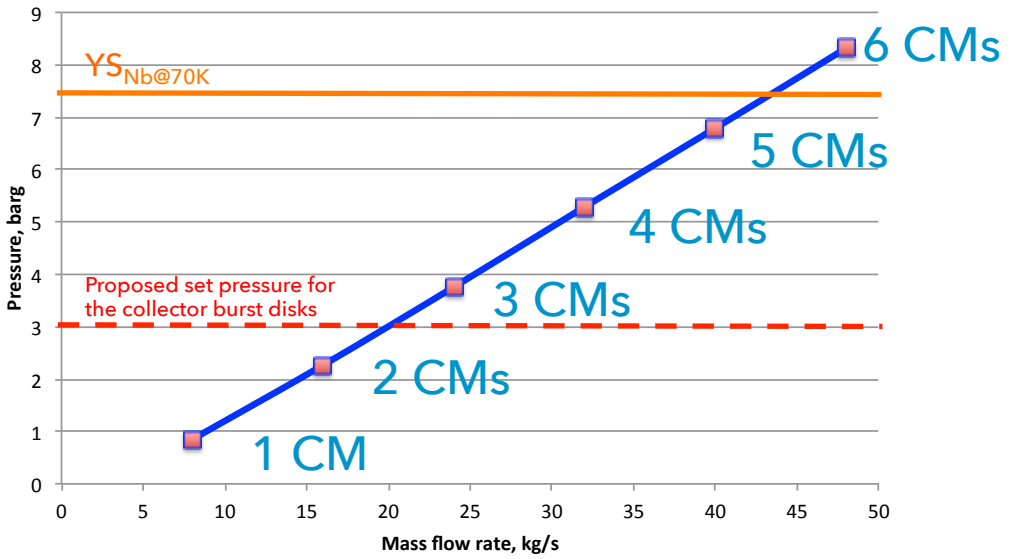
*DN250 vacuum gate valves are designed for 5000 cycles

Collector openings – Burst disks

Yield strength of Niobium versus temperature



Max pressure in the CM versus helium mas flow rate



Estimated temperature of the cavity wall during an accident: 70 K

$YS_{Nb@300K}$ = 80 MPa
$YS_{Nb@70K}$ = 580 MPa (7.2 times higher)

lambda	D	L	m	T	paverage	ro	Dp	Dp
-	m	m	kg/s	K	bar	kg/m3	Pa	barg
0.03	0.267	250	8	20	1.4	3.3719	85035.4	0.9
0.03	0.267	250	16	20	2.1	5.0589	226714.6	2.3
0.03	0.267	250	24	20	2.85	6.8666	375814.6	3.8
0.03	0.267	250	32	20	3.6	8.6742	528889.9	5.3
0.03	0.267	250	40	20	4.38	10.5534	679238.8	6.8
0.03	0.267	250	48	20	5.15	12.4073	831955.7	8.3

Assumption: Stress proportional to pressure load
PS = 1.04 barg
P_{max} = 7.5 barg

⚠ The constraint of the maximum allowable pressure limit from the PED is not considered in the results presented in this slide

Acknowledgement: J.Fydrych

Collector openings – Burst disks

Acknowledgement: J.Fydrych

Component	Unit price	Quantity	Total price
Rupture disks (DN150)	700 EUR	86 pcs	60,200.- EUR
RD holders	1000 EUR	86 pcs	86,000.- EUR
DN250 pipe	80 EUR	800 m	64,000.- EUR
Supports	300 EUR	200 pcs	60,000.- EUR
Hoses DN100	300 EUR	86 pcs	25,800.- EUR
Bellows DN250	600 EUR	60 pcs	36,000.- EUR
Installation	150 EUR	800 m	160,000.- EUR
			492,000.- EUR

+

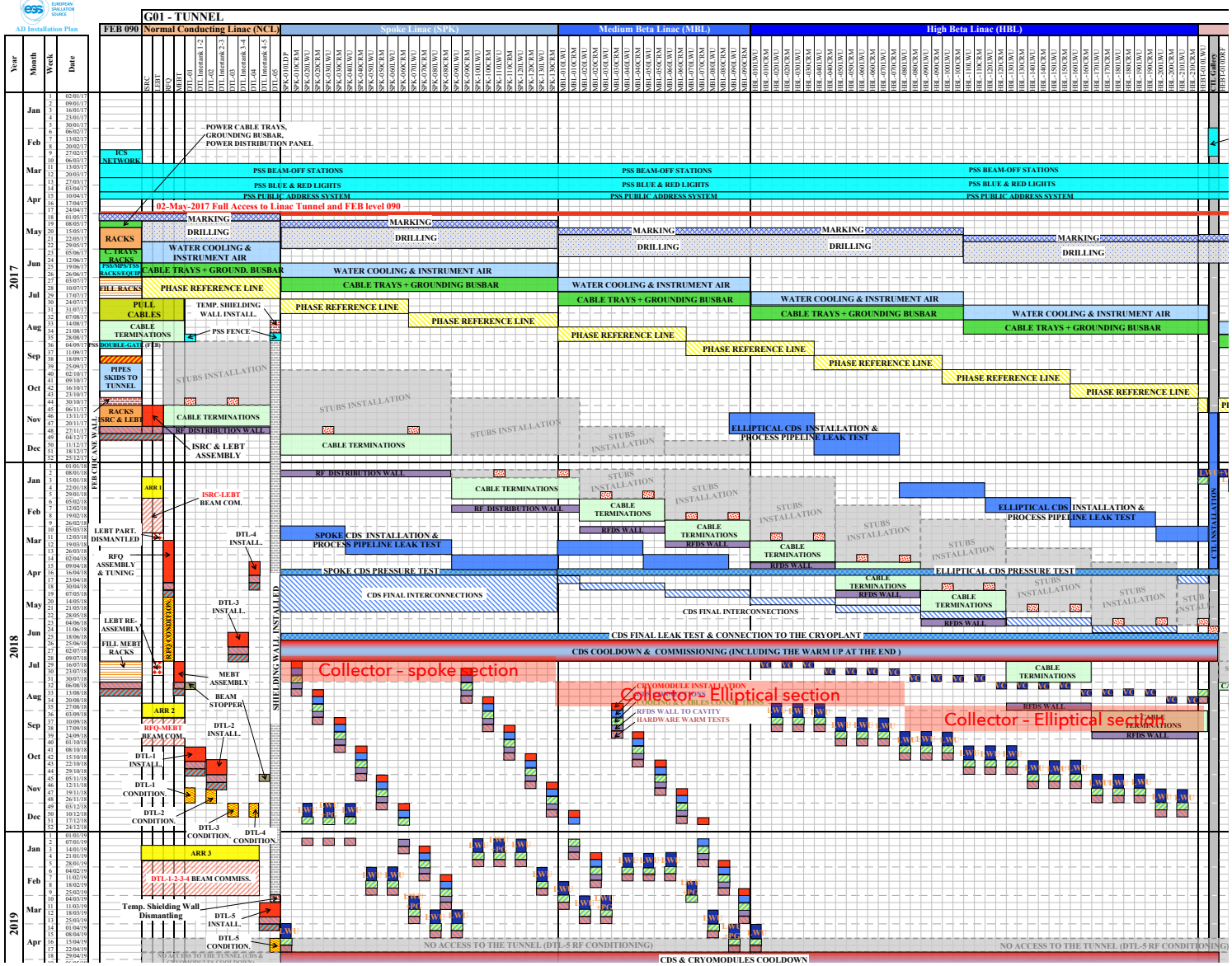
- No (or very limited) maintenance
- Passive device (no controls to manage)
- Cost efficient

-

- Potential impact on the compliance with the applicable PED (maximum allowable pressure)
- Burst disks (cryomodule side) that can withstand high pressure available on the market?
- Potential impact on the design of the cryomodules (i.e. burst disks and diphasic line)?

Helium collector – Time schedule

Acknowledgement: J.Fydrych

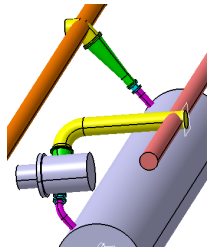


EUROPEAN SPALLATION SOURCE

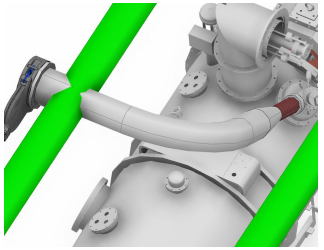
Helium collector project team

J.Moberg, J.Fydrych, E.Lundh, D.Phan & J.Weisend

Next steps

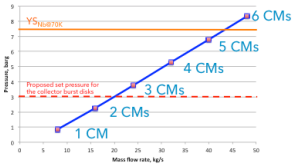


1. ESS to evaluate the design proposal for the Elliptical CM submitted by G.Olivier (IPNO) on March 30th.

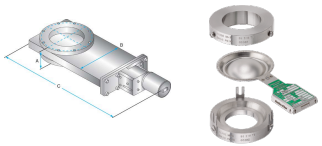


2. ESS to perform new pressure drop calculations in the connection line between the cryomodules' burst disks and the helium collector.

3. IPNO to investigate if burst disks designed to withstand a maximum pressure of 4 bara downstream are available on the market as well as the cost impact. Also, the potential impact on the cryomodules design shall be assessed

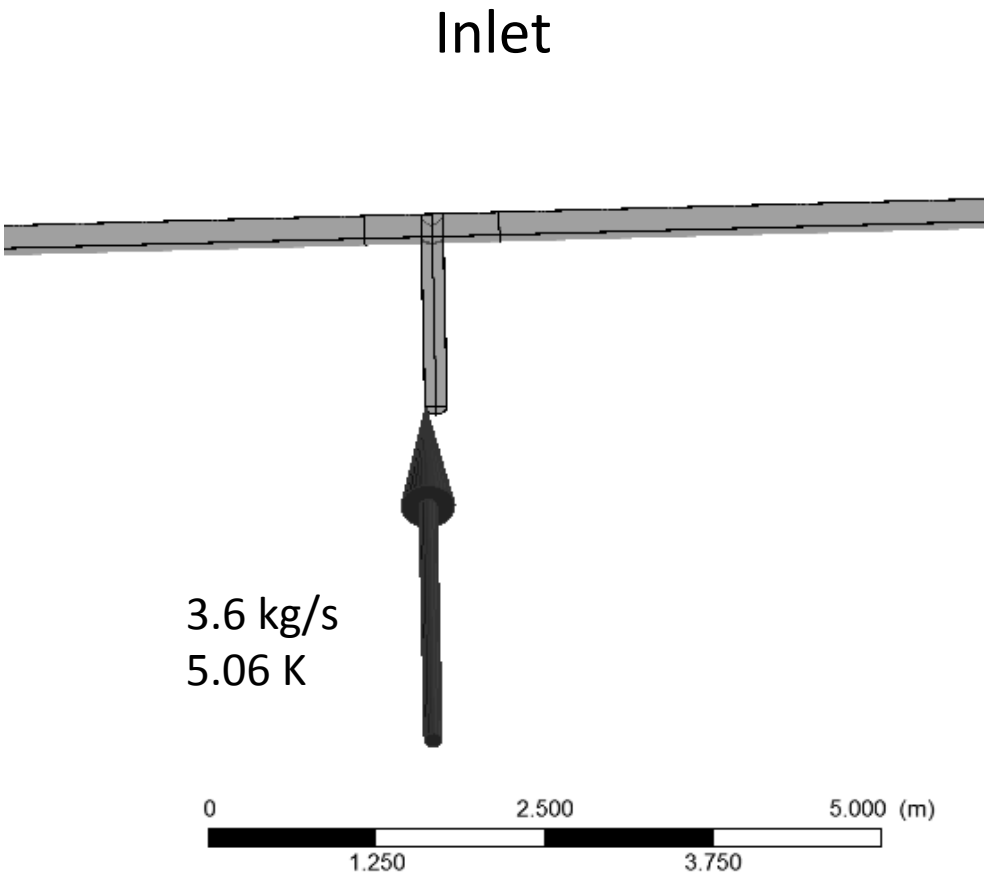


4. ESS to make make a final decision regarding the engineering solution for the perforation of the helium collector in the coming weeks.



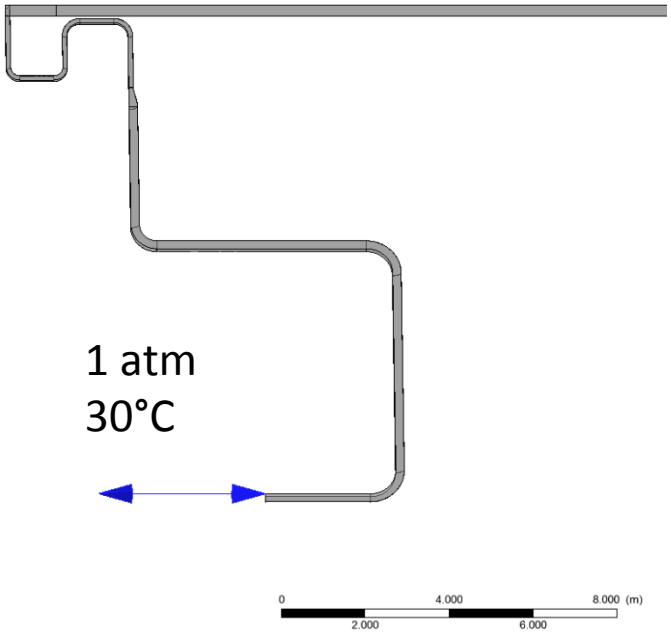
Simplified Geometry

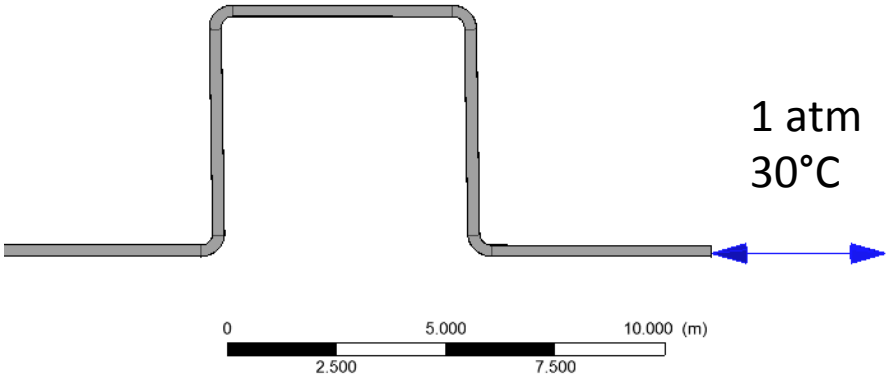
Boundary conditions, Elliptical cryomodule



Boundary conditions, Elliptical cryomodule

Outlets





Tunnel-Pipe-Helium boundary