Cryostats

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On behalf of the FREIA team

FREIA Laboratory, Uppsala University

8th of May 2019

Contents

- Introduction and main concepts
- Horizontal cryostat HNOSS
- Vertical cryostat Gersemi
- Double spoke cryomodule
- Cold boxes

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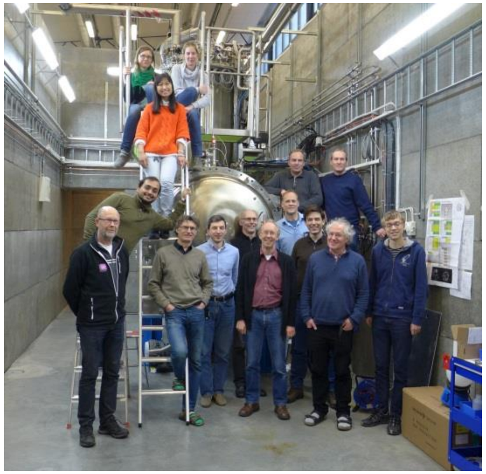
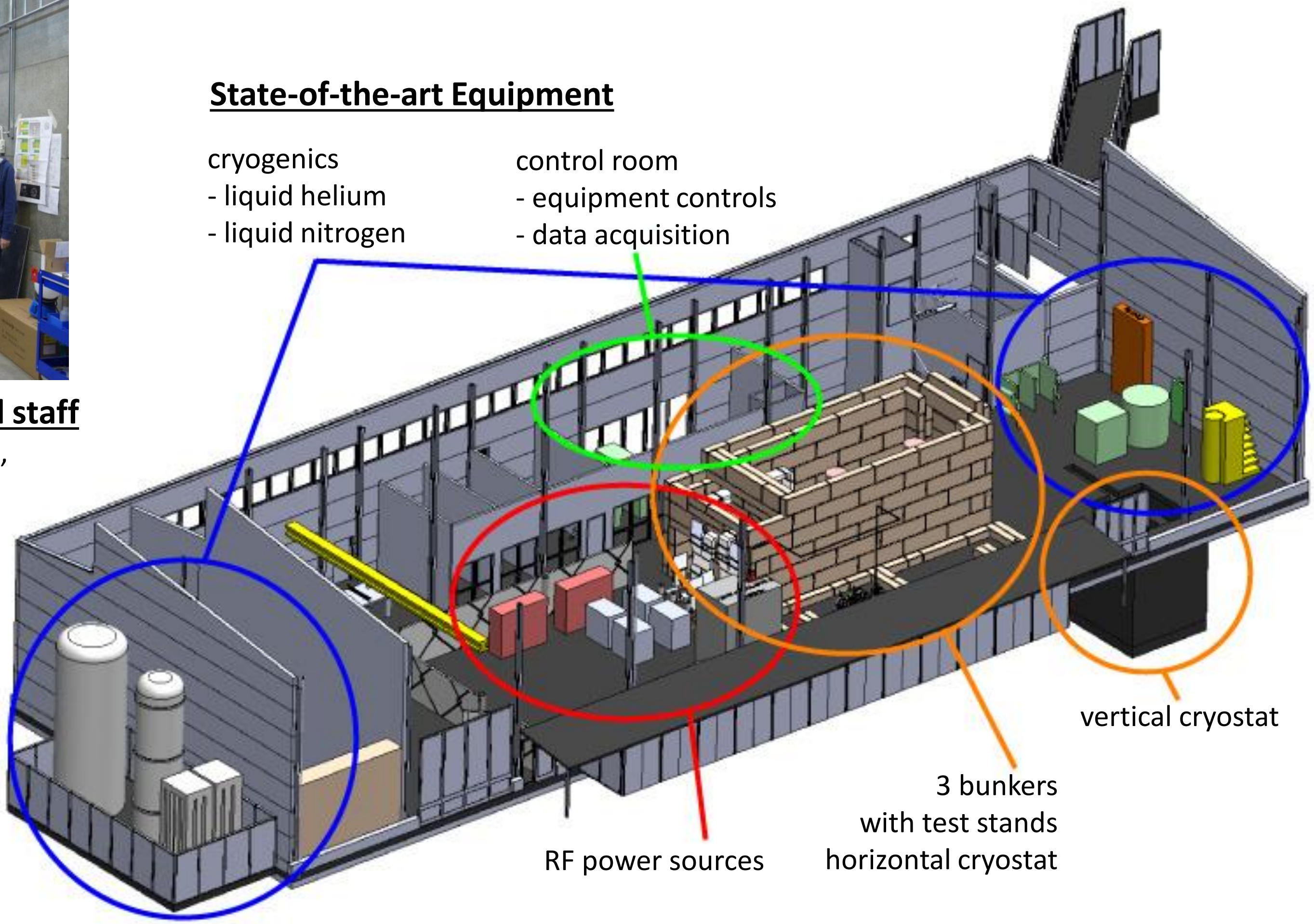
What and Whom?

Facility for Research Instrumentation and Accelerator Development



Competent and motivated staff
collaboration with physics (IFA), engineering (Teknikum), TSL and Ångström workshop

Funded by KAWS, Government, Uppsala Univ.



FREIA Collaborations

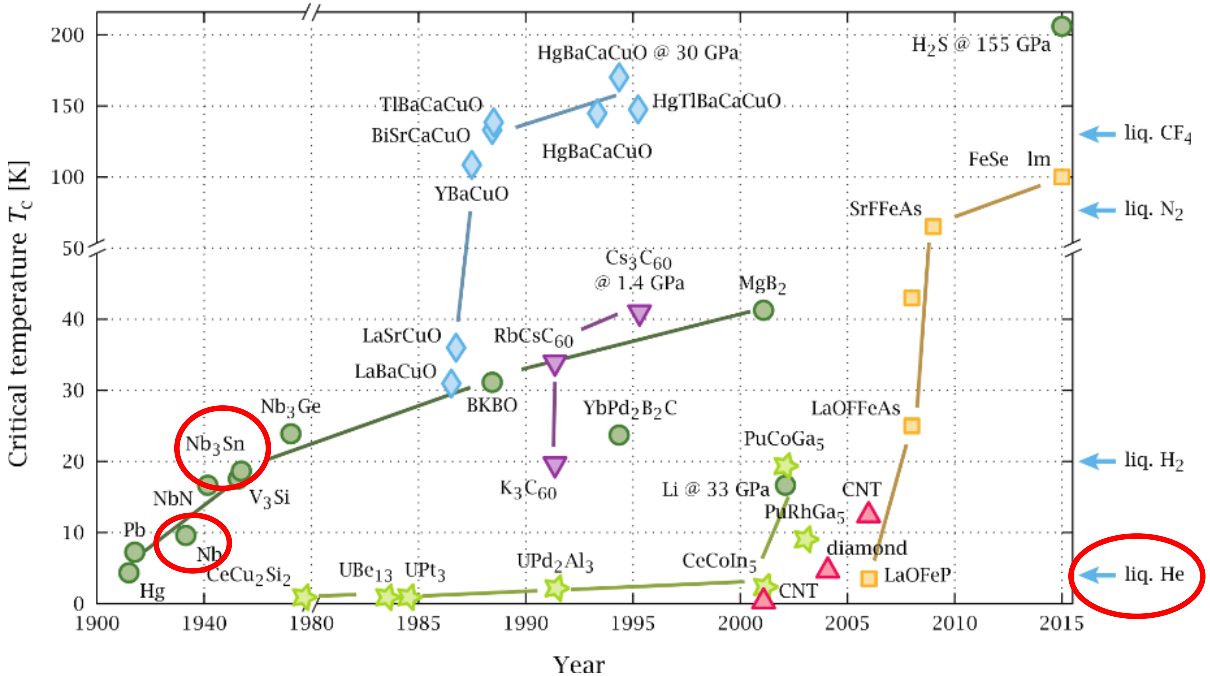
- FREIA has collaborations to test the following:
  - Superconducting (SC) double spoke cavity for ESS (done)
  - Superconducting (SC) high beta elliptical cavity for ESS (done)
  - Cryomodules housing two superconducting double spoke cavities for ESS (ongoing)
  - Superconducting dipole magnets for CERN Hi-Lumi project (to start at the end of the year)
  - Superconducting cold boxes for CERN (together with RFR Solutions)

Superconductivity

SC materials offer almost no electrical resistance → Lower heat disipation in the material

Cavities
- Less heat to the cavity
- More power available for the beam

Magnets
- Wires conduct much larger electric currents
- More intense magnetic fields



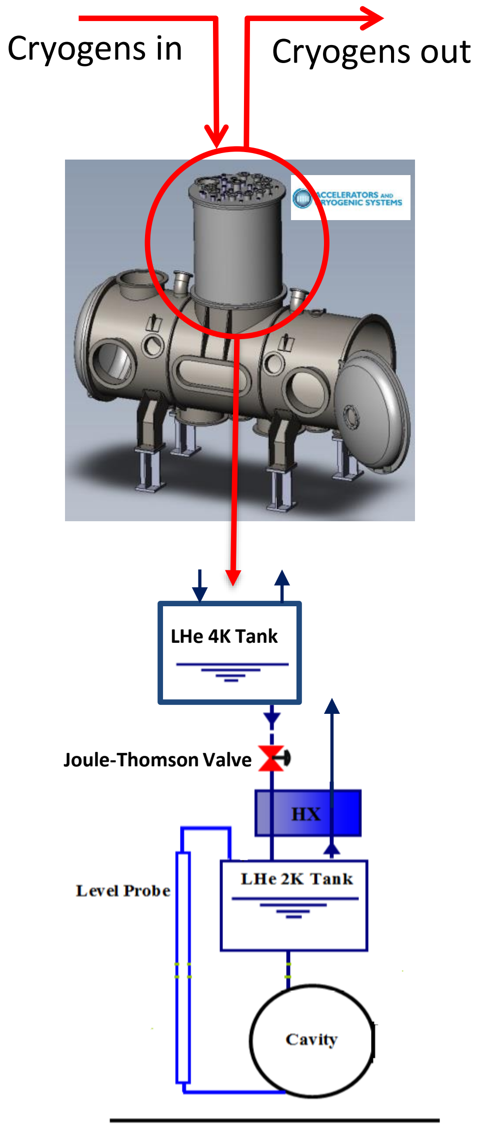
Source:
https://en.wikipedia.org/wiki/Superconductivity#/media/File:Timeline_of_Superconductivity_from_1900_to_2015.svg

- Helium liquefaction plant
- Using LHe/GHe means a recovery system

$T_{operation}$ = 2 K (31 mbar)

Superfluid He

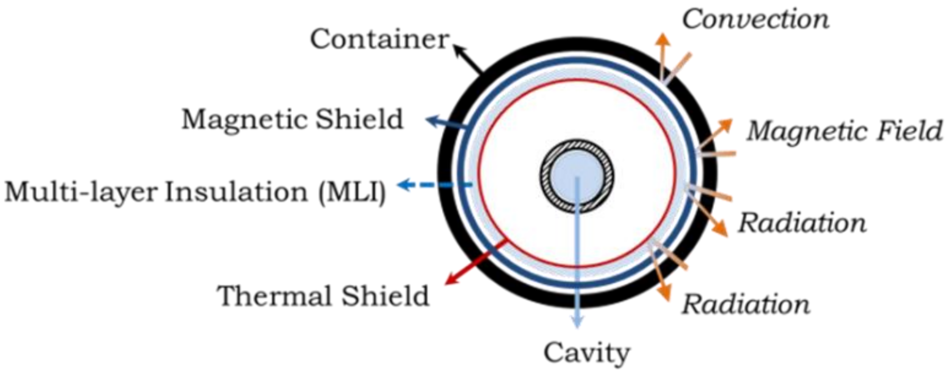
Cryostat Fundamentals



- Main conversions

  P_{plug} = 1 kW to generate 1 W cooling power at 4.2 K

  $V_{GHe\ at\ 293\ K} = 700\ V_{LHe\ at\ 4.2\ K}$



- Minimise the amount of heat that reaches the cold parts, i.e. the device under test (DUT)
  - Convection → vacuum
  - Radiation → thermal shield, multilayer insulation
  - Conduction → thermal anchors

Cryostats: General Components

- Vacuum vessel
  - Main container, outermost component
  - Under vacuum. A high vacuum (≤10^{-5} mbar) already reduces the heat into the cold parts by 90%

- Thermal shield
  - Blocks the thermal radiation
  - Works as a thermal anchor or heat sink for the equipment connected to room temperature, like valves and cable instrumentation linking to equipment placed at lower temperatures
  - Usually cooled via LN_2 or GHe at a certain temperature

- Multi layer insulation (MLI)
  - Further reduces the radiation heat
  - Might help in an event of vacuum insulation loss
  - Wrapped around the thermal shield, the DUT, etc.

- Magnetic shield
  - Made of a high permeability material
  - Reduces the effect of the earth's magnetic field on the cavities
  - Can be placed at any temperature
  - Unless removable cannot be in place while testing magnets: saturation

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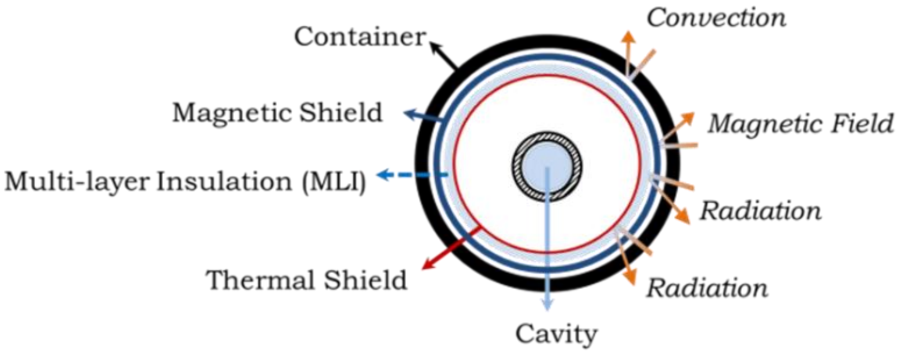
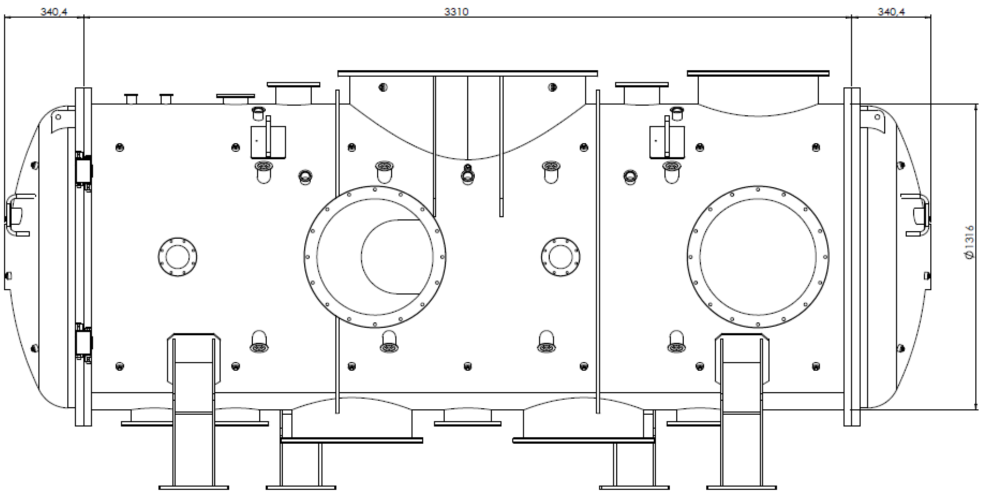
HNOSS

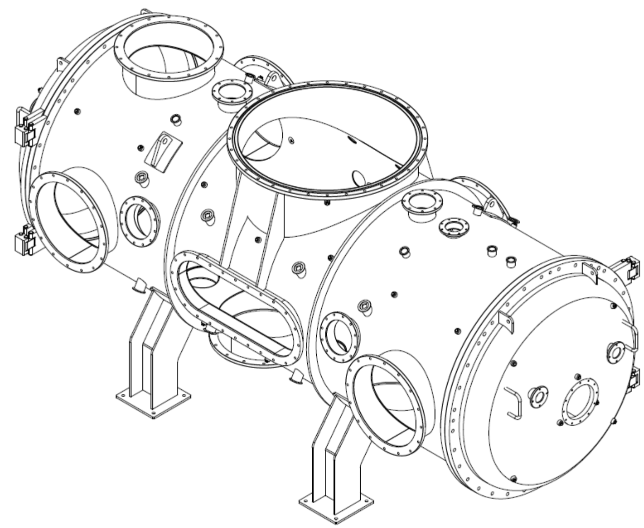
Total volume ca. 7 m^3

- Purpose: test of superconducting cavities
- Has two parts:
  - Valvebox (VB): contains all the valves and tanks and most of the piping
  - The cryostat itself (HCS): houses the cavities and the table
- Both parts have:
  - Magnetic shield (room temperature)
  - Thermal shield (LN_2 temperature)

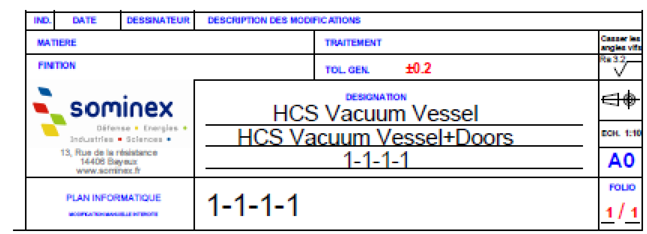


Vacuum Vessel

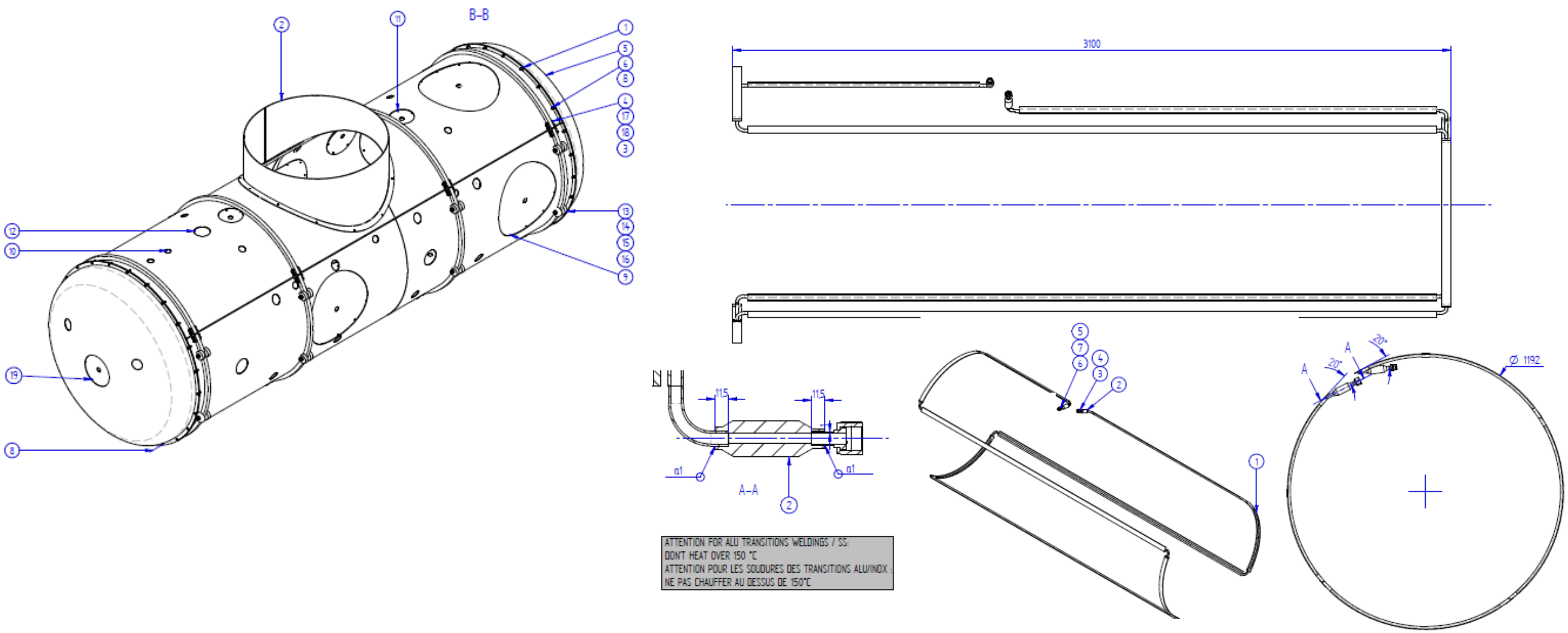




- Material: 304L
- Flange types (high vacuum): ISO F, ISO K, ISO KF
- Flange types (ultra high vacuum): ISO CF



Thermal Shield

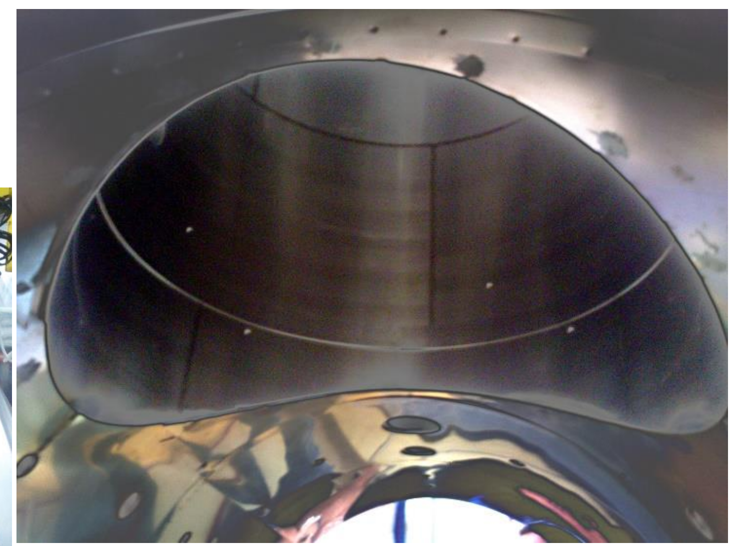


- Material: Al (EN 573-3 AW6060T6)
- Other usual material: Cu (more expensive, more weight but better σ_{th})
- Cooling pipes: Aluminium (omega-type pipes)
- Transition between Al (thermal shield) and SS (pipes from the valvebox)
- Thermal shield not continuous

Magnetic Shield

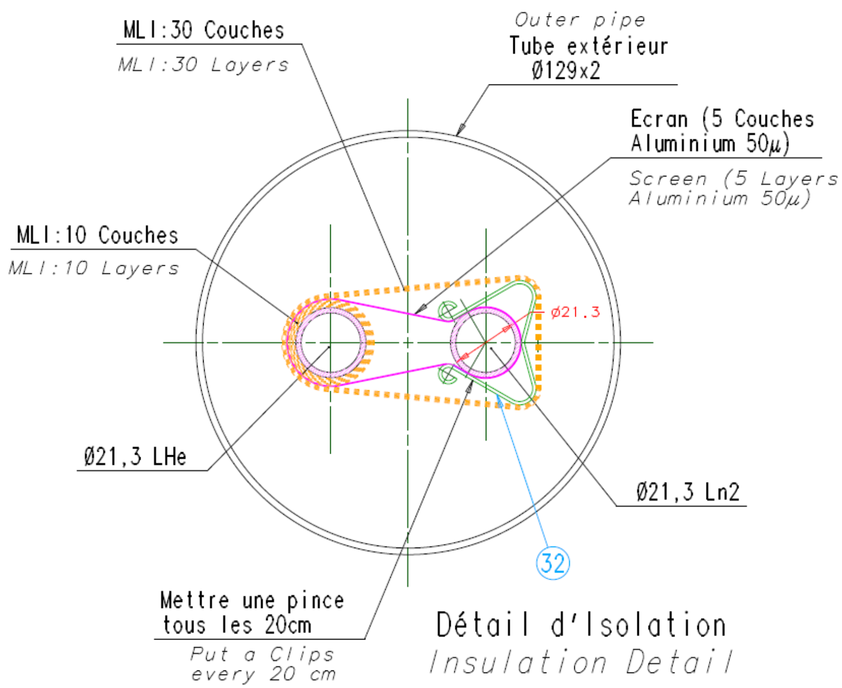
- Made of several parts of mu-metal (high permeability material) welded together
- The material is made into shaped and placed on a furnace following a certain procedure to activate the material
- This material is very sensitive to further handling: those parts of the material exposed to work will lose the magnetic properties





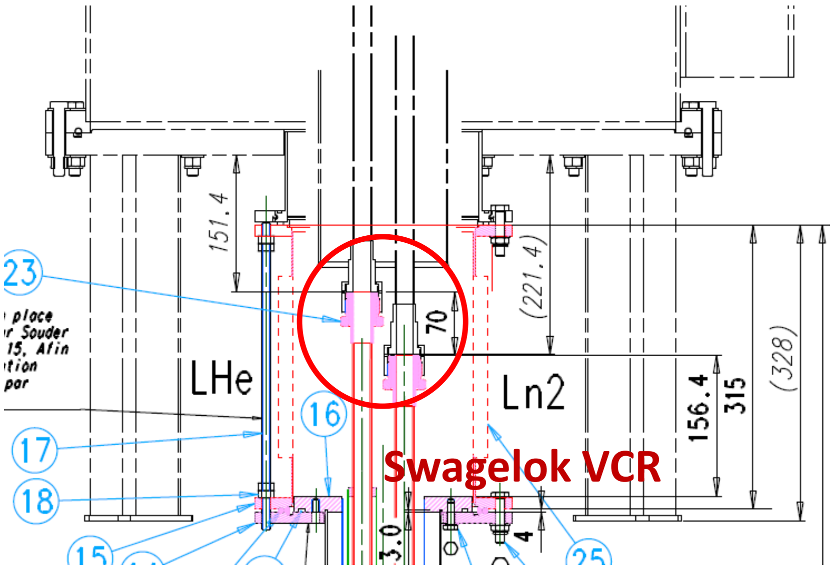
Transfer lines

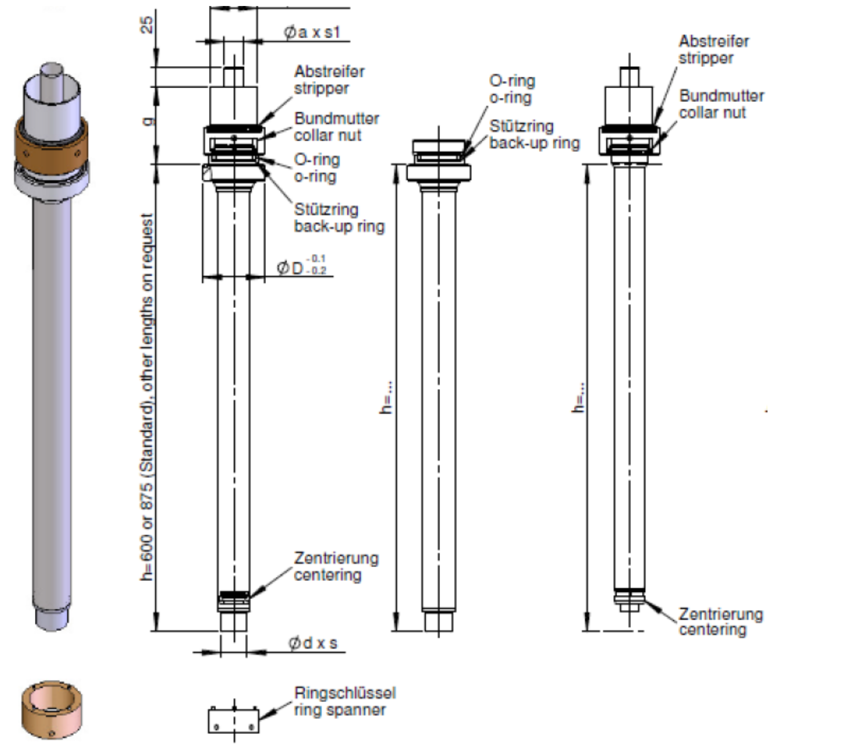
- Material: SS
- Space between the transfer line and the cooling lines
- LN2 and LHe line separated, not touching
- Insulation material: multilater insulation (MLI)
- Usually under vacuum



Transfer Lines: Couplings

- For cryogen transfer (LN2, LHe)
- Swagelok VCR:
  - Requires less space
- Bayonet:
  - Lower heat leak (small sizes), thus more efficient in transfer
  - Provide a vacuum insulated joint
  - More expensive
- CF connections:
  - Only to be used if need to remove for every test





Bayonet **Female** **Male**

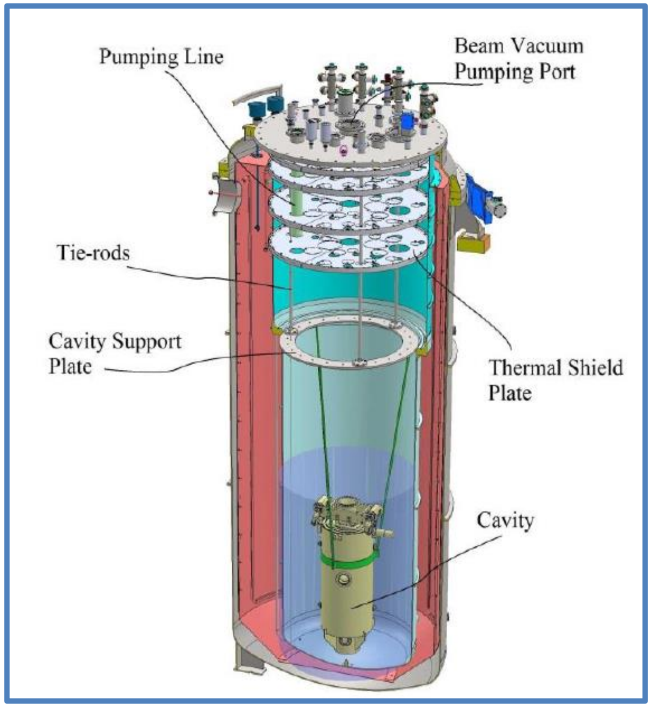
CF gasket

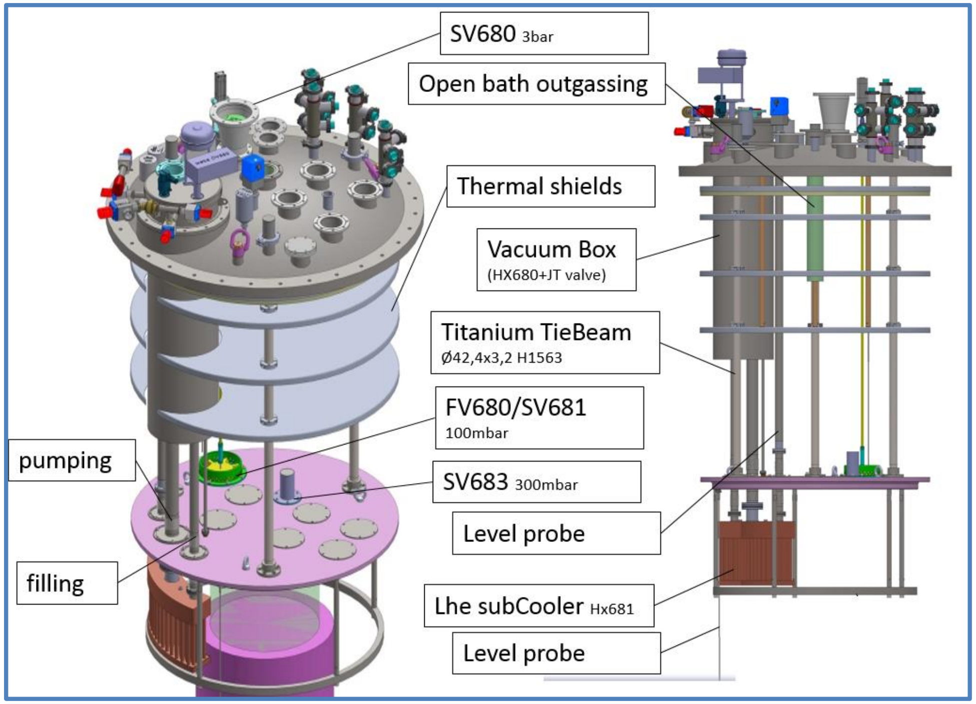
Picture taken from Kurt Lesker

Contents

Purpose

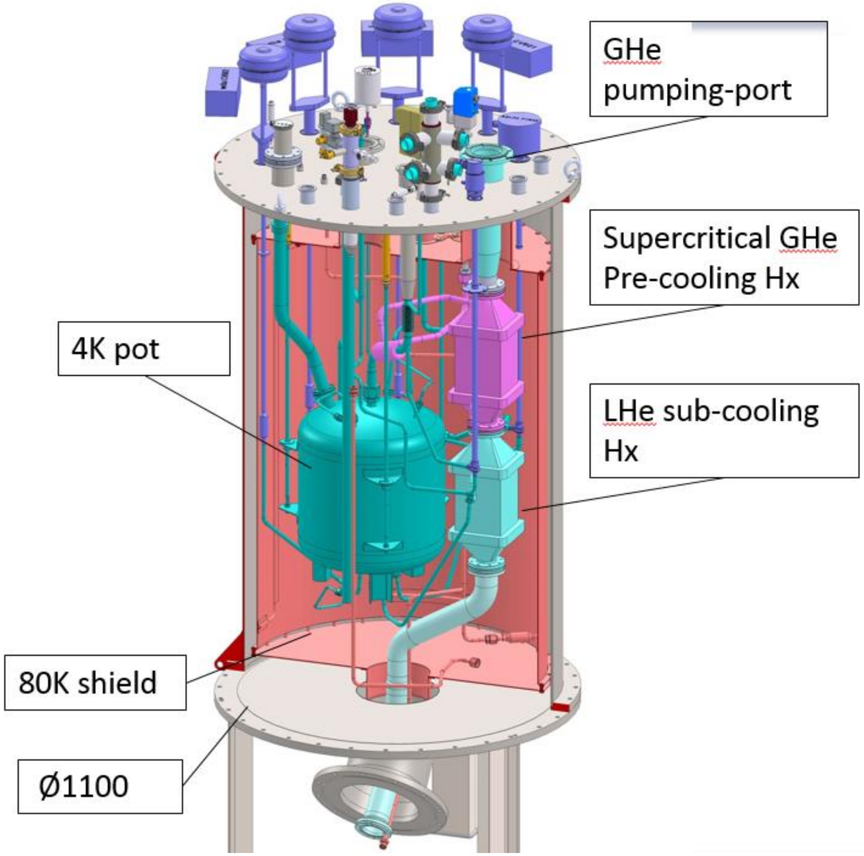
- To test superconducting magnets (max 2kA)
- To test superconducting cavities





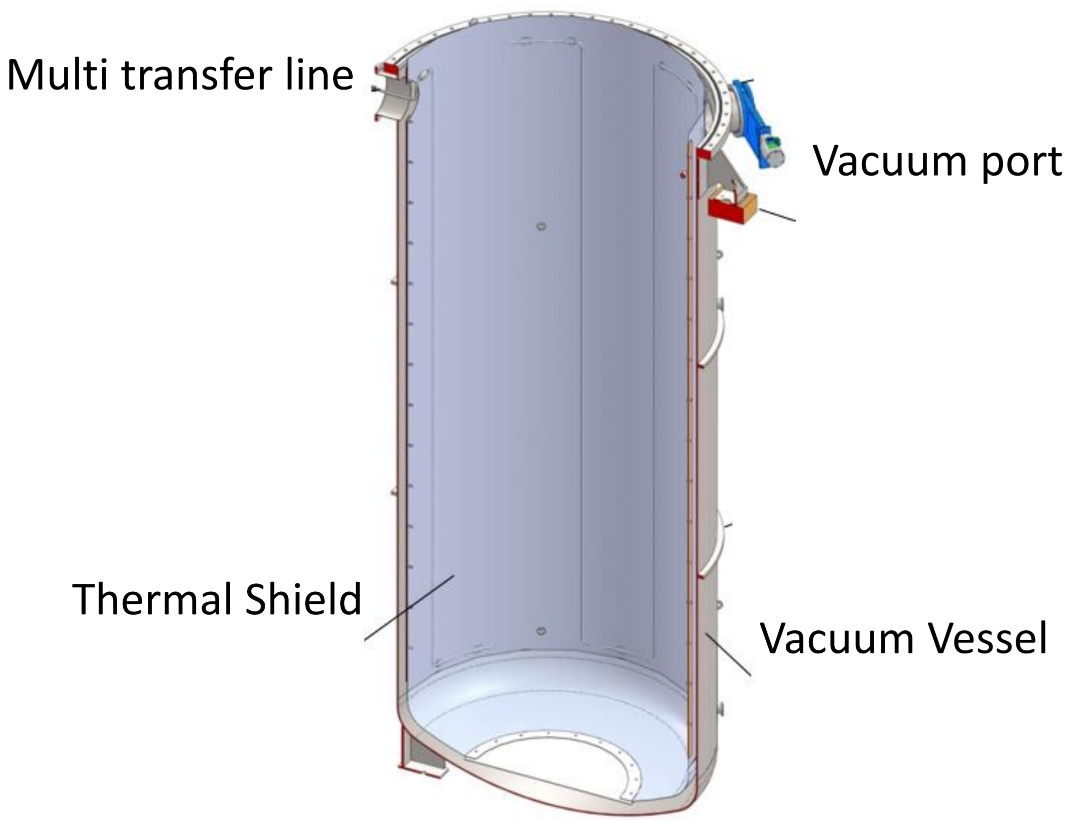
Valvebox

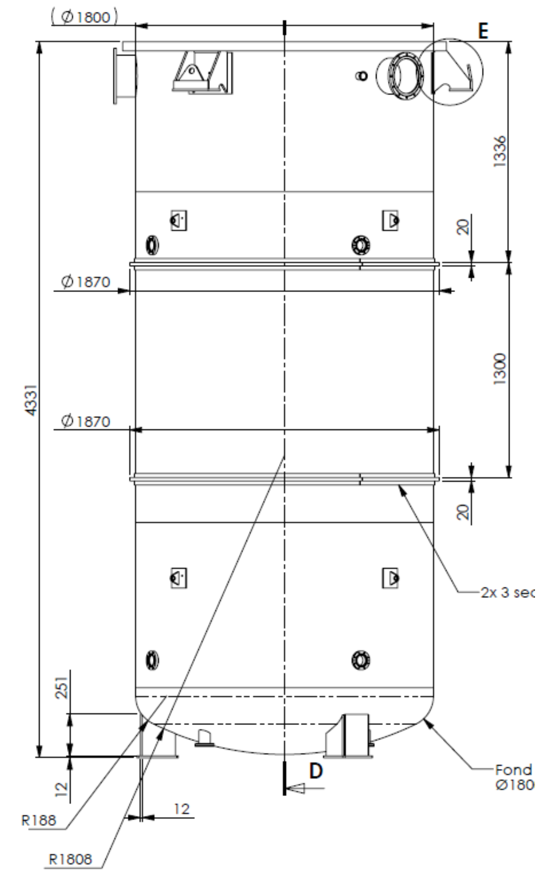
- Used to deliver the cryogens to the cryostat
- Height: 2300 mm
- Vacuum Vessel Material: SS
- Thermal shield material: Cu
- Flange types (high vacuum): ISO F, ISO K, ISO KF



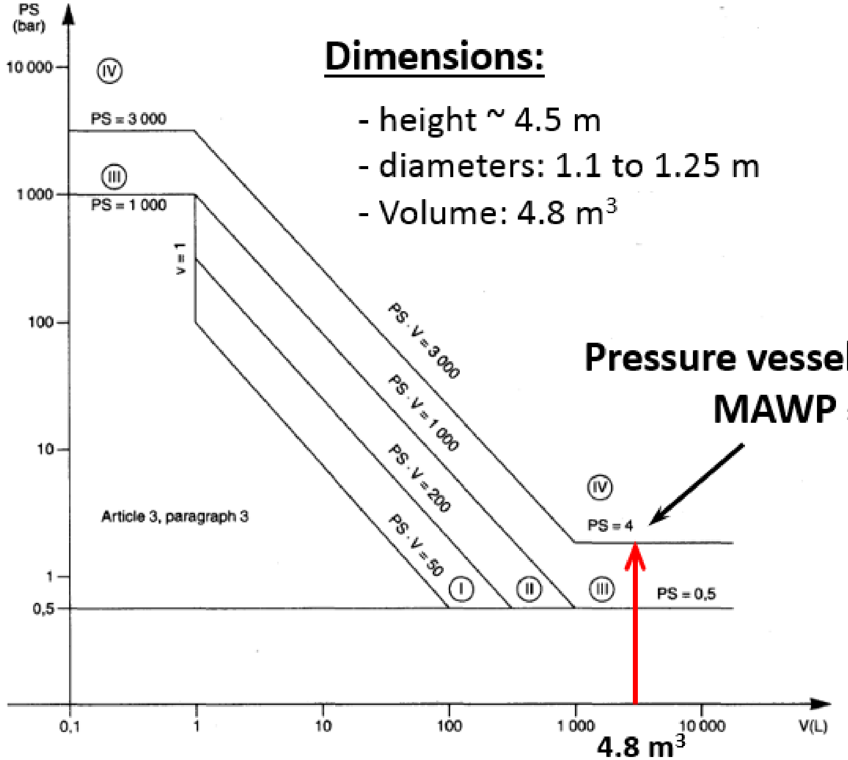
Vacuum Vessel and Thermal Shield

- Vacuum Vessel Material: SS
- Thermal shield material: Al
- Thermal shield not continuous
- Flange types (high vacuum): ISO F, ISO K, ISO KF





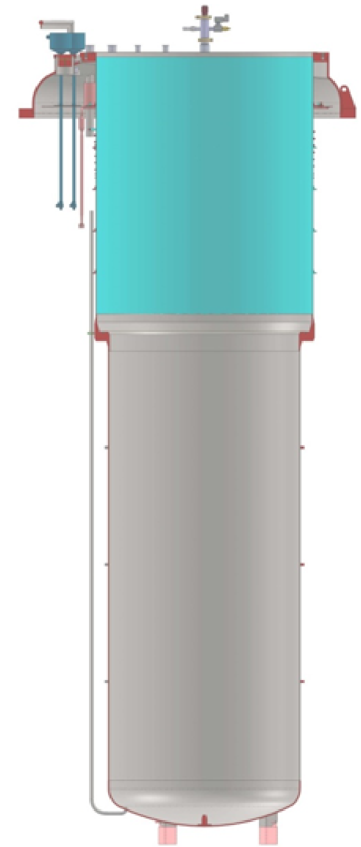
Pressure Vessel



Dimensions:

- height ~ 4.5 m
- diameters: 1.1 to 1.25 m
- Volume: 4.8 m^3

Pressure vessel of category III, MAWP ≈ 4 barg



Specifications:

- Maximum allowable operating pressure: ≈ 4 barg,
- Hydraulic test pressure: 7.15 bara,
- The mechanical calculations refer to EN13445 and EN13458 norms

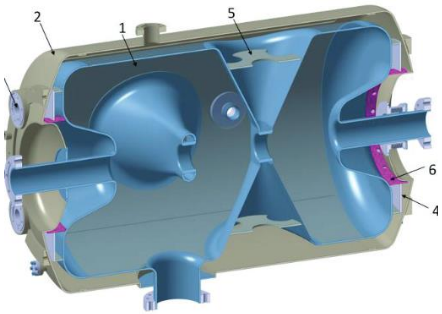
Norms:

- EN13458: Cryogenic vessels
- EN13455: Unfired Pressure vessels

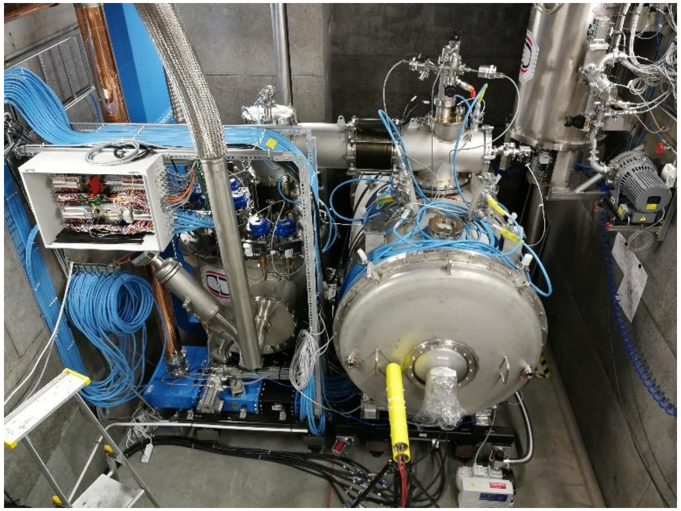
Contents

Purpose

- The spoke cryomodule section at ESS will increase the protons beam energy from 90 to 216 MeV
- This section
  - Is supercoducting
  - Is 56 m long
  - Has 26 double spoke cavities
  - In 13 cryomodules

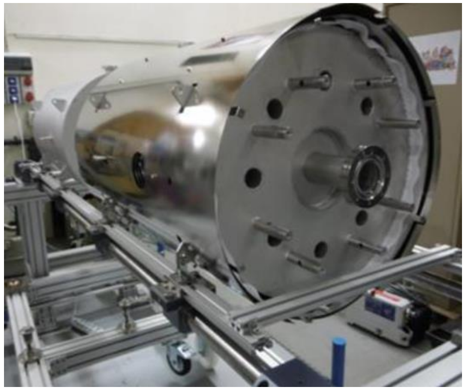


Source: P. Duchesne et al. "Design of the 352 MHz Beta 0.50 double s poke cavity for ESS", Proceedings of SRF2013, Paris, France (FRIOC01)

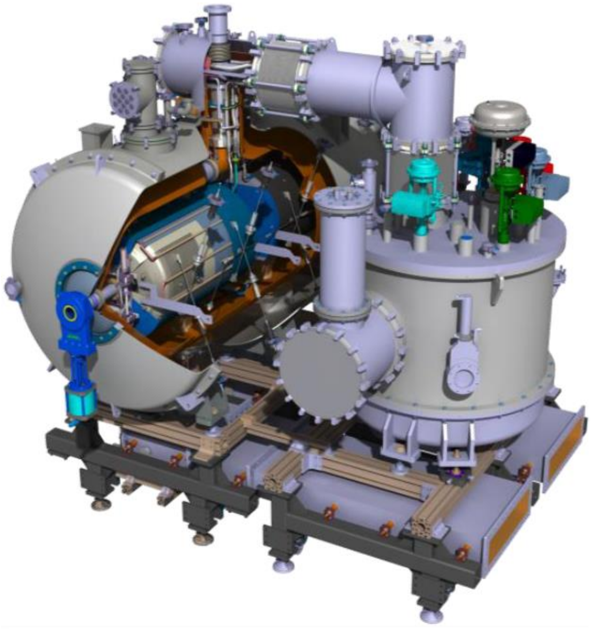


Components

- It is a specialized version of HNOSS



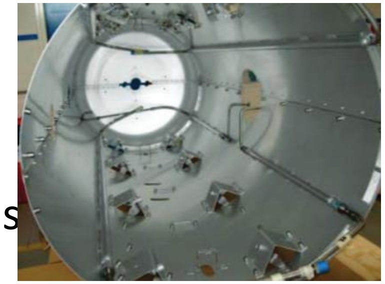
Source: P. Duthil et al. "Design and Prototyping of the Spoke Cryomodule for ESS" Proceedings of HB2016, Malmö, Sweden, WEAM4Y01



Source: P. Duthil et al. "Design and Prototyping of the Spoke Cryomodule for ESS" Proceedings of HB2016, Malmö, Sweden, WEAM4Y01

- Has two double spoke cavities inside
  - hanging from tie-rods
  - each has a magnetic shield around
- Thermal shield made of Al, cooled via LN_2

  Note: For ESS cooling is with GHe (no LN_2 available)
- The prototype has more instrumentation than the series cryomodules



Source: G. Olry et al. "Recent Progress of ESS Spoke and Elliptical Crymodules", Proceedings of SRF2015, Whistler, BC, Canada (TUAA06)

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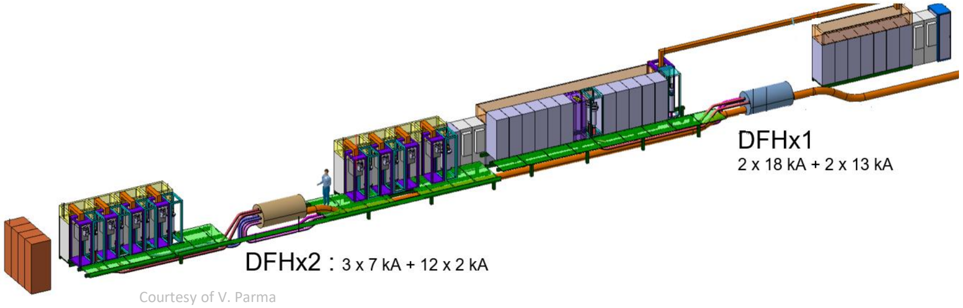
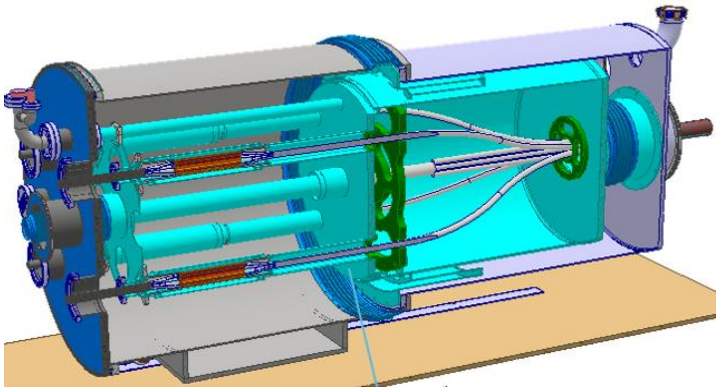
Purpose

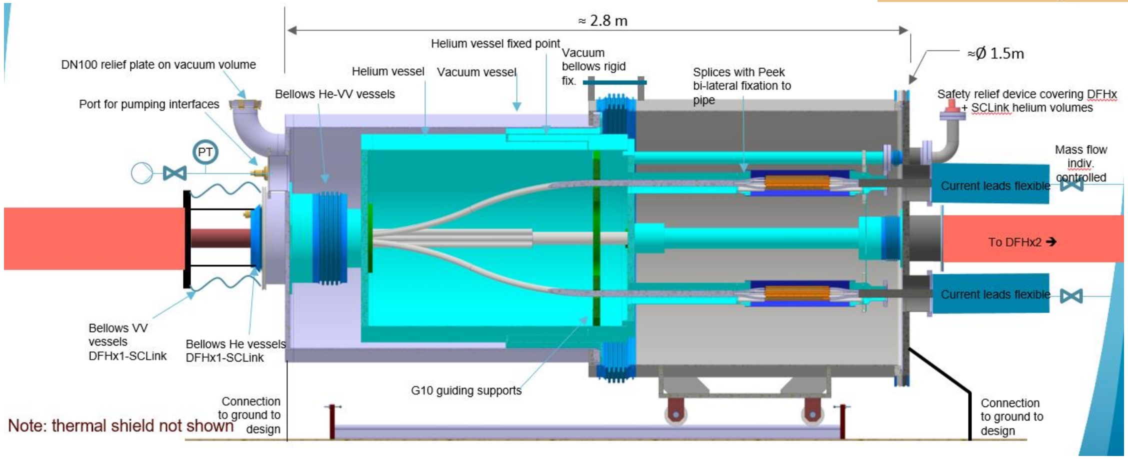
- Interconnection (splices) and cooling of superconducting cables
- Preliminary design, in collaboration with RFR Solutions



Courtesy of V. Parma



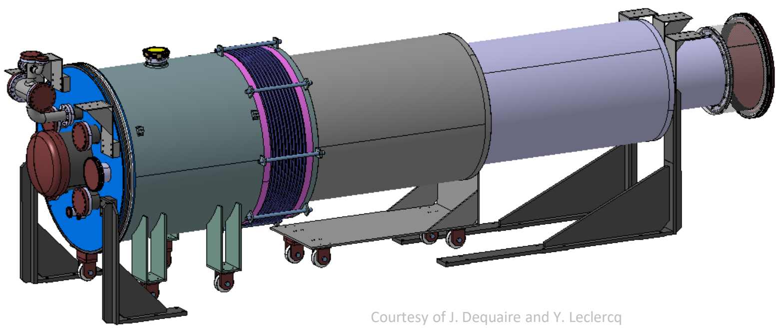
Courtesy of V. Parma



Courtesy of V. Parma

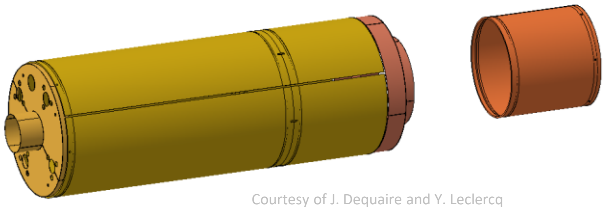
Components

- The vacuum vessel
  - Made of SS (304L or 316L)
  - Independently sliding parts to provide access to internal components
  - Flanges : ISO-K, ISO-KF, CF type
  - Tube thickness : about 6 mm



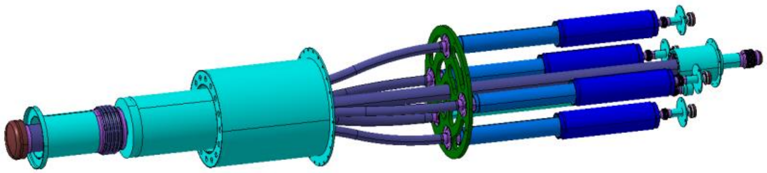
Courtesy of J. Dequaire and Y. Leclercq

- Thermal shield
  - Made of Al alloy or Cu alloy
  - Half tube thickness : 2 mm



Courtesy of J. Dequaire and Y. Leclercq

- The SC cable vessel
  - Made of SS 316L
  - Mass flow of helium below 17 K
  - The design pressure is 4 bar
  - Flanges : CF type
  - Tube thickness : about 3 mm

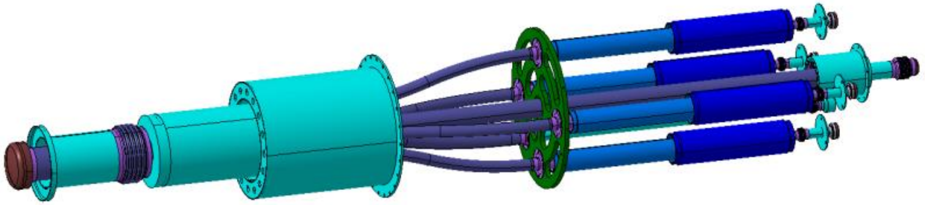


Courtesy of J. Dequaire and Y. Leclercq

THANK YOU
for your
ATTENTION

Helium Vessel

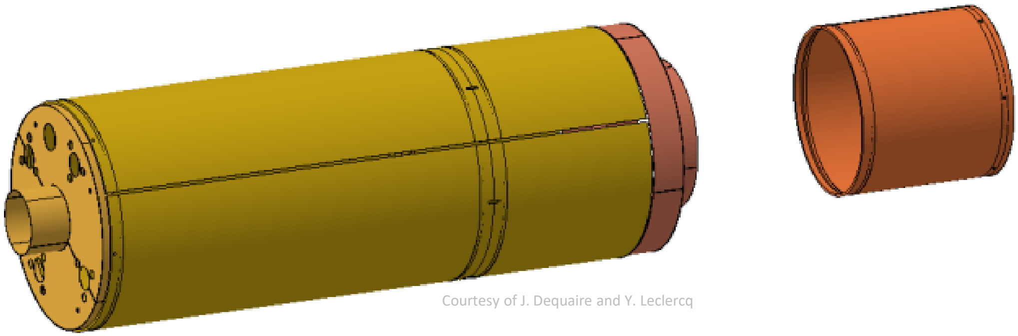
- The internal envelope of the DFH cryostat contains the superconducting cables in a gaseous mass flow of helium below 17 K. The design pressure is 4 bar.
- The helium vessel is composed of a main vessel and several smaller vessels connected in between by flexible hoses. The smaller vessels are composed of double sleeves to allow access on either side.
- Formed bellows ensures the compensation of thermal contractions
- Material :
  - Helium vessel : 316L (1.4404 or 1.4435)
  - Bellows : 316L (1.4404 or 1.4435, Note: 316Ti not allowed)
  - Flexible hoses with braids : 316L (1.4404 or 1.4435)
  - Supports : Composite epoxy/glass fiber : G10
  - Conflat flanges : 316LN 3D forged (CERN procurement)
  - Fasteners : A4 degreased (silver plated for dedicated application)
  - Conflat fasteners : A4-100 degreased
- Leak tight welds :
  - Welds shall be full penetration and qualified to the PED requirements
  - TIG welds (141 or 142)
- Flanges : CF type
- Tube thickness : about 3 mm



Courtesy of J. Dequaire and Y. Leclercq

Thermal Shield

- Composed of three independent shields made in thermal conductive material.
- Material :
  - Thermal shield : Aluminum alloy to be defined or copper alloy
  - Fasteners : A2, A4, Aluminum
- Assembly:
  - The shields must be half shelled
- Half tube thickness : 2 mm



Courtesy of J. Dequaire and Y. Leclercq

Equipment

- Safety valves
  - possible closed volumes (betwen valves)
  - closed volumes (vacuum vessel)
- Bellows
- Cryogenic valves
  - Depending on where they sit they should be thermalized
  - For LHe used WEKA or VELAN
  - For LN2 use SELFA
- LHe level probes from American Magnetics Inc.
- Temperature sensors
  - From Troom to 30 K: normal Pt100
  - From Troom to 1.4 K: CERNOX
- Heaters for flat surfaces: thin film MINCO or OMEGA
- Heaters for gas outlets: heater cartridges from VULCANIC
- Cable connectors (Burndy, Lemo, etc.)