EUROPEAN SPALLATION SOURCE

The ESS Cryomodules

2012 December, 5th

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Cryomodules Lead Engineer

Outlines

ESS accelerator context for a Globe of Science and Innovation

- Main parameters and milestones
- Cryomodule stakeholders

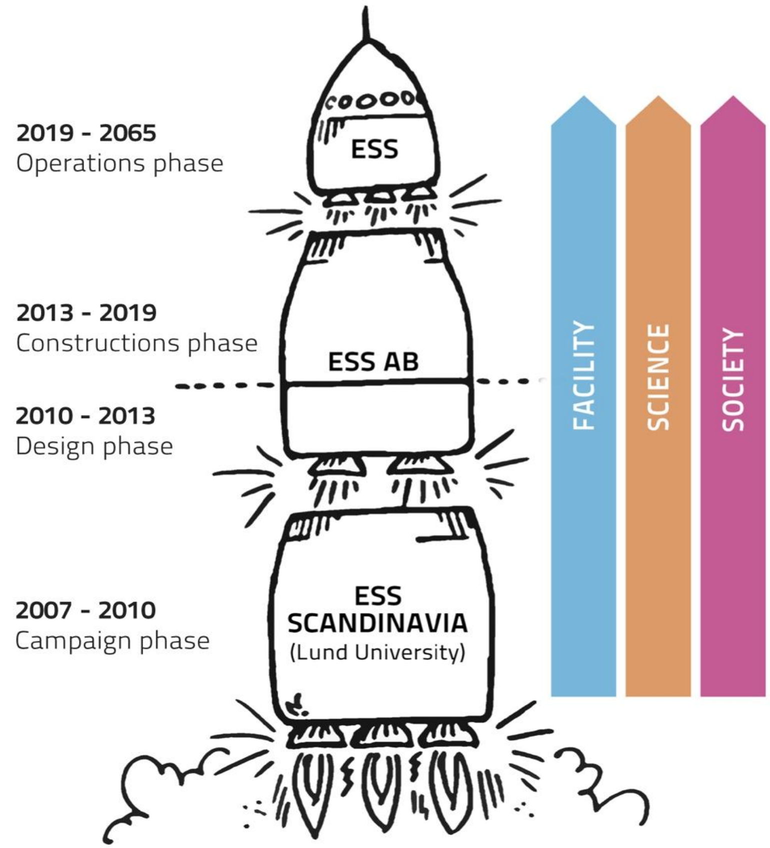
Cryomodule strategy

- Functions and constraints
- Technology Demonstrators
- Spoke cavities technologies
- Elliptical cavities technologies

The ESS philosophy

See Giobatta Lanfranco's talk

- Vision & Raison d'etre: Science for Society
- Mission:
  - Design, construct and operate the worlds-leading neutron source
  - Manage the company business
- Core Values:
  - Excellence; Openness; Sustainability
- ESS philosophy:
  - "Greenfield thinking on a greenfield site"



ESS phases and themes of communication

Goal: to deliver first neutrons before this decade is out
→ Goal oriented project

ESS – some numbers

Superconducting Proton Linear Accelerator (500 m)

2.5 GeV Proton Energy

50 mA (2 mA) peak (average) proton current

357 kJ/pulse

2.86 msec pulse length

14 Hz pulse frequency

71.4 msec periods between pulses

5MW proton beam power

Single Target Station

Rotating Tungsten, helium cooled

22 instruments

High reliability, low losses

ESS Accelerator context

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The Goal for WP4 and WP5

From design, procurement to test of spoke, high-beta and medium-beta elliptical:

- Technology demonstrators
- Series cavity packages
- Series cryomodule packages

= The Planning

2016			2017				2018				2019				2020				2021				2022				
Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1

- First Access to Upgrade space (test stand)(g)
- Beam Liscense available (g)
- Cryo-plant buildings for test stand ready (g)
- Full Access to Accelerator Building (Gallery and tunnel) (g)
- Target Building access (g)
- Target Cryoplant comissioned (g)
- Normal conducting beam commissioning starts
- 80MeV protons available
- Super conducting beam commissioning starts
- Medium Beta systems ready
- Spoke systems ready
- 630 MeV Protons available
- High Beta systems ready
- First Proton to Target (g)
- End of Construction ACCSYS

+ The People

ADU WP (2010-2012)


Romuald Duperrier (30 years ago)


Steve Peggs


Cristina Oyon


David McGinnis


Pierre Bosland


Mats Lindroos


Guillaume Devanz

CEA - Saclay

Work Package (work areas)

1. Management Coordination – ESS AB (Mats Lindroos)
2. Accelerator Science – ESS AB (Steve Peggs)
(3. Infrastructure Services – now ESS AB!)
4. SCRF Spoke cavities – IPN, Orsay (Sebastien Bousson)
5. SCRF Elliptical cavities – CEA, Saclay (Guillaume Devanz)
6. Front End and NC linac – INFN, Catania (Santo Gammino)
7. Beam transport, NC magnets and Power Supplies – Århus University (Søren Pape-Møller)
8. RF Systems – ESS AB (Dave McGinnis)
19. P2B: Test stands – Uppsala University (Roger Ruber)


Roger Ruber

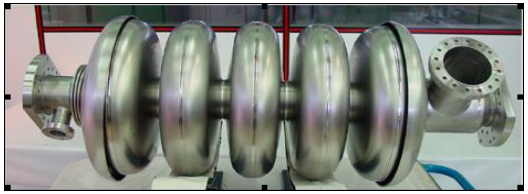
UPPSALA UNIVERSITET


Søren Pape Møller


Santo Gammino


Sebastien Bousson

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY



Accelerator

See Sebastien Bousson's talk

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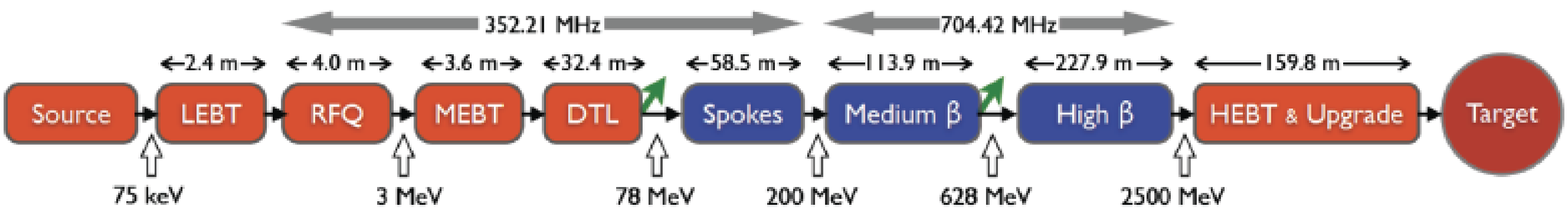


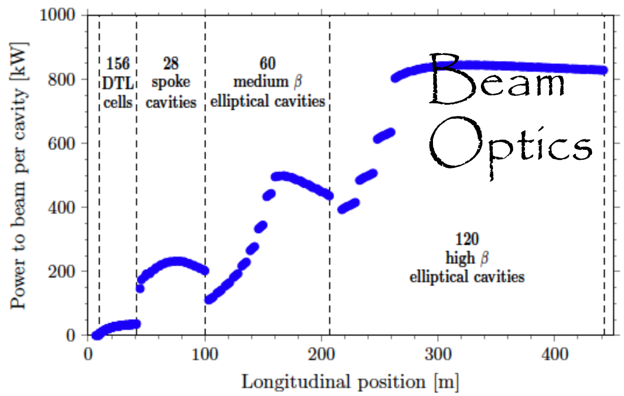
→ 98 % of the accelerator is superconducting

Section	Number of modules	Frequency MHz	Input energy MeV	Cavs. per module	Cavs. per sector	Module length m	Sector length m
Spoke	14	352.21	79	2	28	2.9	58.5
Medium-beta	15	704.42	201	4	60	5.6	113.8
High-beta	30	704.42	623	4	120	6.7	227.9
Total	59				208		400.16

Parameter	Unit	Value
Energy	GeV	2.5
Current	mA	50
Pulse length	ms	2.86
Pulse repetition frequency	Hz	14
Average power	MW	5
Peak power	MW	125

Cryomodule stakeholders - Interfaces

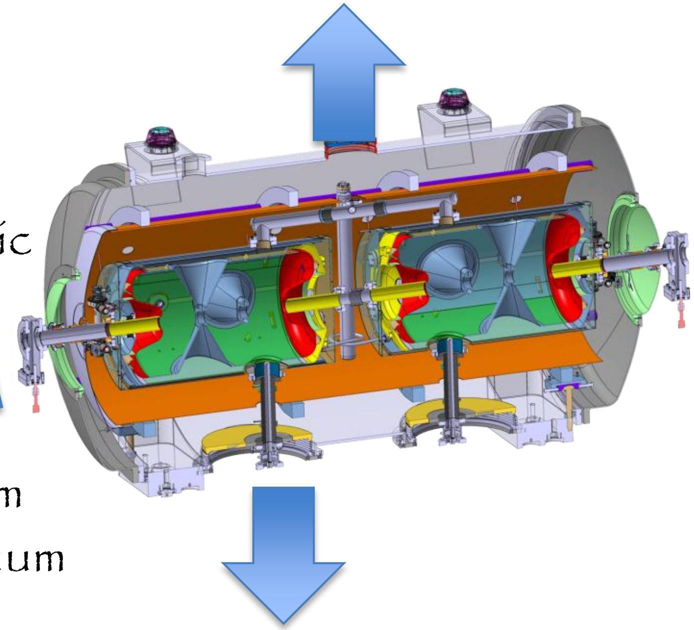
- ESS cold linac integrators (e.g. cryogenics, vacuum, conventional facilities)
- Safety team
- Cryomodule designers
- Cavity package designers
- Control and instrumentation teams
- Component assembly teams
- Test teams
- ESS system engineer
- Survey experts
- Toolings
- Transport



Beam Optics

Beam Diagnostic

Cryogenic distribution



Beam Vacuum

Radio-frequency

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- Elliptical cavities technologies

Cryomodule Functions

→ Cavity package (incl. SRF cavity, Ti helium tank, cold tuning system, and fundamental power coupler)

→ Cryomodule package :

- The supporting and mechanical systems that interface the cavity packages in the test area than in the tunnel
- The vacuum vessel, thermal and magnetic shieldings that insulate the cavity packages from the ambient condition
- The cryogenic distribution (hydraulic circuits, jumper connection) that interfaces the cavity packages with the cryogenic valve box (CTL, cryoplant)
- The instrumentation, control valves and the safety devices

Construction phase (2013 – 2019)

→ Technology demonstrators to proof the series production technologies
→ Cavity package
→ Cryomodule package

- Design to complete following the Accelerator Design Update (ADU phase)

- Procurement
  - Product Breakdown Structure, materials

- Conditioning and Assembly
  - Power coupler conditioning, surface processing, clean room and hall assembly

- Test with cryogenics and RF environment
- Tunnel installation
- Commissioning
- Operation

Constraints

Integrated hazards due to operating environment:

- Radiation environment (high intensity proton beam)
- Cryogenic temperature: 2 K (Helium II), cryogenic vessel, pressure vessel
- Sub atmospheric condition (31 mbar saturated), leak-tightness
- Magnetic environment (14 mGauss)

Main challenges:

- Quality: science and innovative using the SRF cavities
- Quantity: 208 cavities and 59 cryomodules
- Short project time scale
- Limited budget
- Series to ease and enable industrialization process

Staged Approach:

- 630 MeV protons to target 3Q 2019
- Staged to nominal power will occur in 3 shutdowns in 2020-2022

Standards and Safety Culture

Engineering standards

- CEN, European Committee for standardization
- SIS, Swedish Standard Institute
- ISO, International Organization for standardization
  - → e.g. European Directive 97/23/CE; EN ISO 4126, PED
  - → ESS guidelines for pressure vessel modeled after FNAL , CERN expertise

Radio-Protection and Rad-hard equipment

- As low as reasonable achievable (ALARA)
- Passive and active safety measures (safety barrier)
- Personnel Protection System, Machine Protection System (IEC61508)

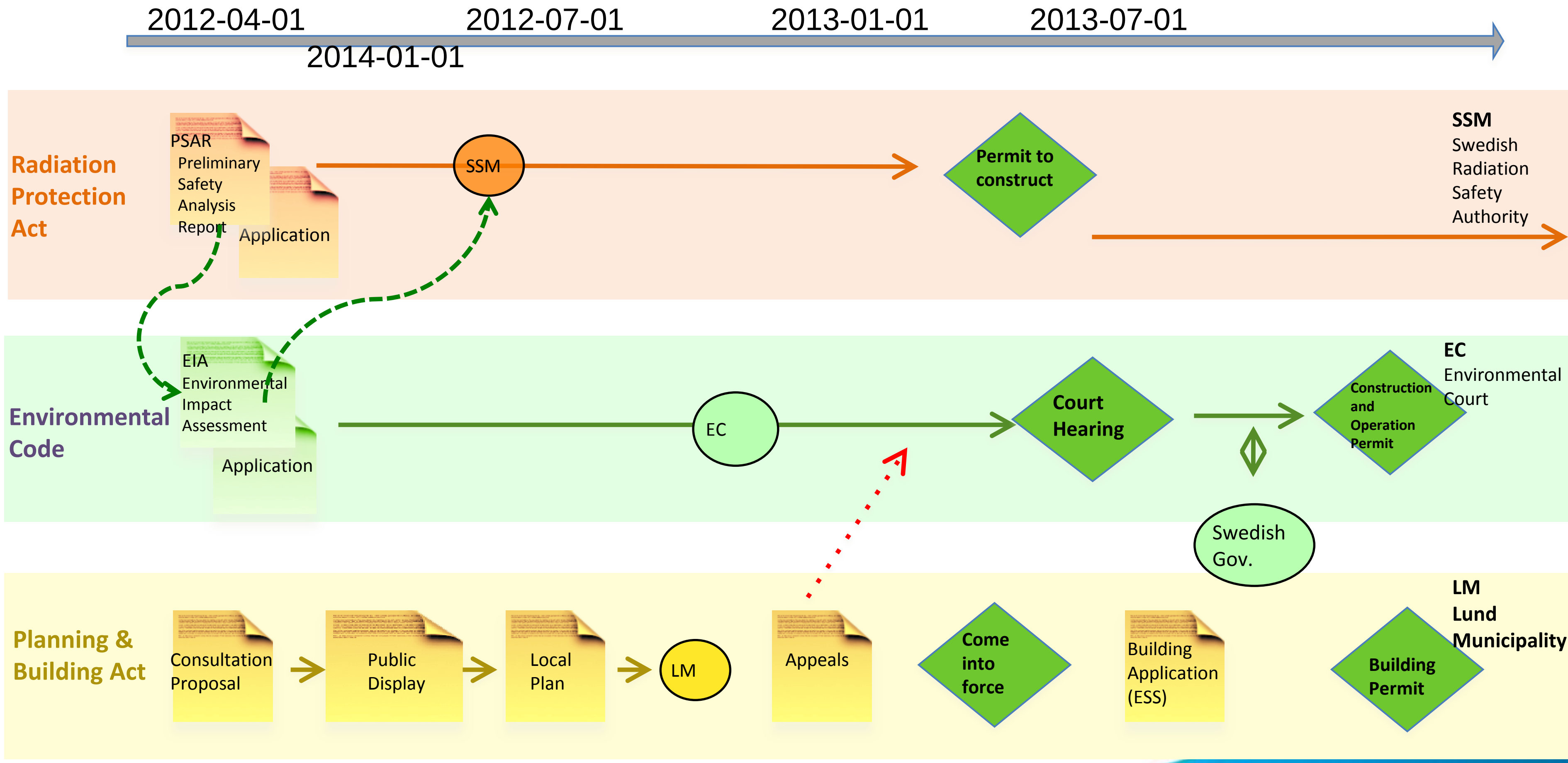
Risk analysis and reliability study

Safety reviews

Quality Assurance

ESS Radiation Safety - Time Schedule

Courtesy of Peter Jacobsson - Head of ESS safety



TDR data

	Temperature K	Pressure MPa
SRF Helium tank	2	0.0031
Power coupler double-wall	5 to 150	0.14
Thermal shield	40-50	1.9

Heat load 4.5 K equivalent, W	**Static**	**Dynamic**	**Beam losses**	**Total**
Spoke resonator	17.5	18.0	8.7	44.2
Medium-beta	27.0	67.3	17.1	111.3
High-beta	29.4	82.0	20.1	131.5
Linac sub-totals	1530	3722	981	6233

Table 4.14: Heat load distribution per cryomodule (4.5 K equivalent).

Sector	**2 K W**	**5 K W**	**50 K W**	**4.5 K equivalent W**
Spoke resonator	5.0	na	35.0	17.4
Medium Beta	6.7	1.5	75.0	26.9
High Beta	7.5	1.5	75.8	29.4

Table 4.15: Static heat load distribution for each temperature levels.

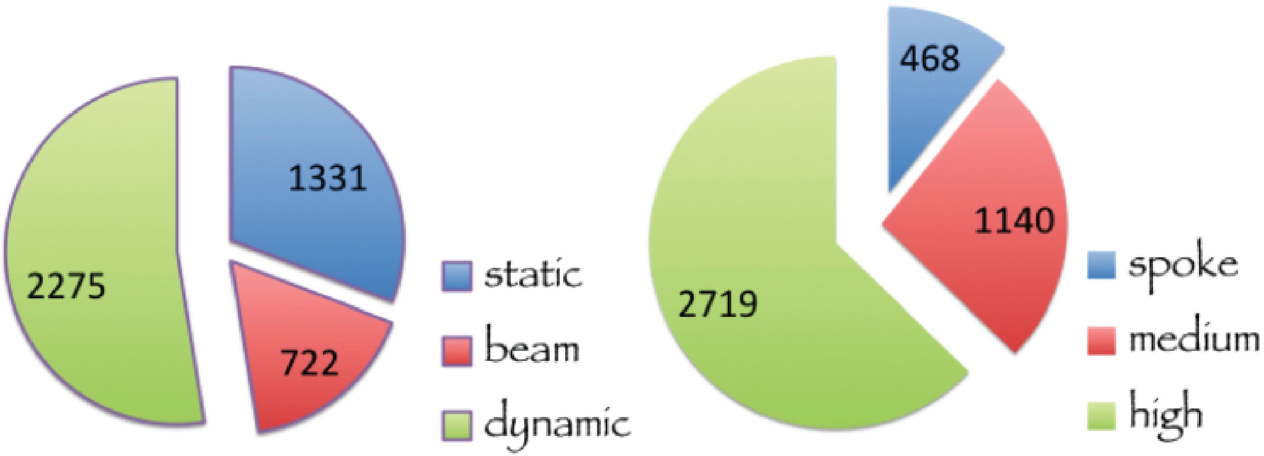


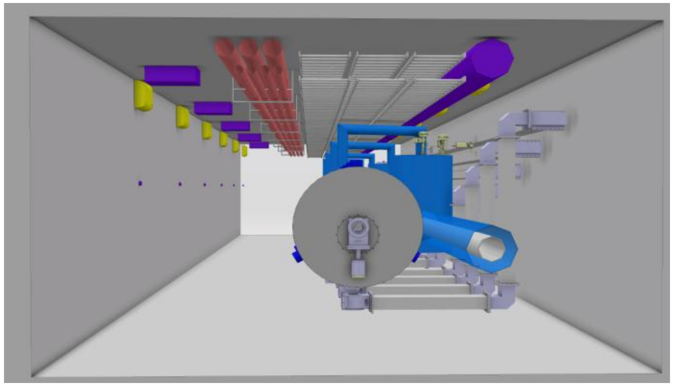
Figure 4.67: Load distribution (static, dynamic and beam losses)

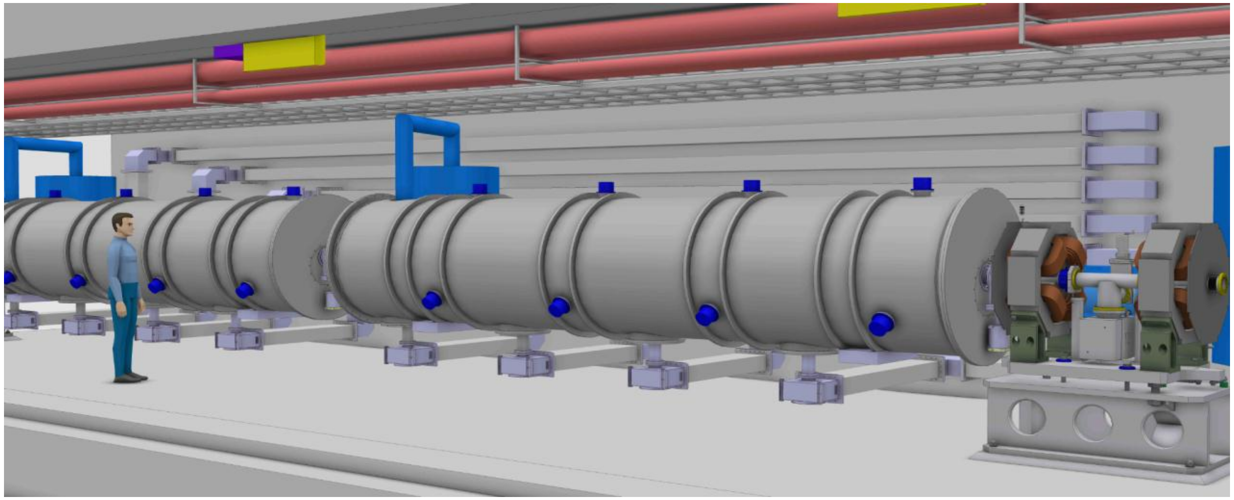
Cryomodule instrumentation

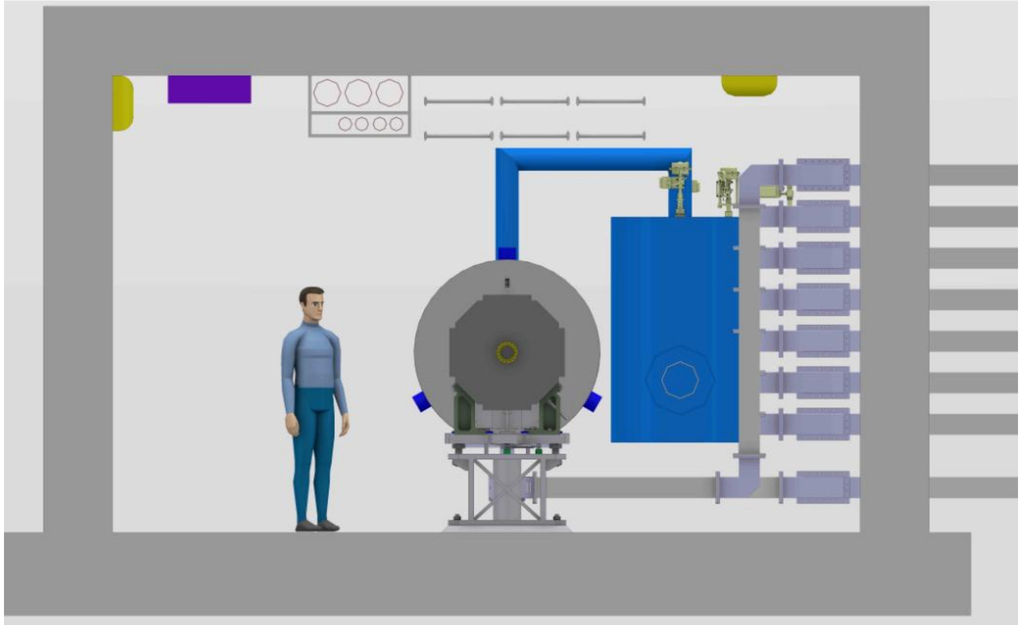
* Instrumentation function
  - Monitoring
  - Control
  - Interlock
  - Alarms

- Expected categories
  - temperature transmitter: Cernox and PT100
  - vacuum gauge
  - pressure gauge
  - level gage
  - control valve
  - flowmeter
  - pick up coil
  - heaters

Tunnel integration







Cavity Cryomodule Technology Demonstrators

→ One Technology Demonstrator per cavity family to validate:

- Fabrication and industrialization of the cryomodule:

e.g. cleaning, tooling, assy procedures, QA;

- The performance of the RF design:

e.g. characterize the cavity RF signature; validate RF results obtained in vertical cryostat;

- The performance of the thermal and vacuum design:

eg. cool-down rate, operating conditions; heat loads; cooling scheme efficiency, leak tightness;

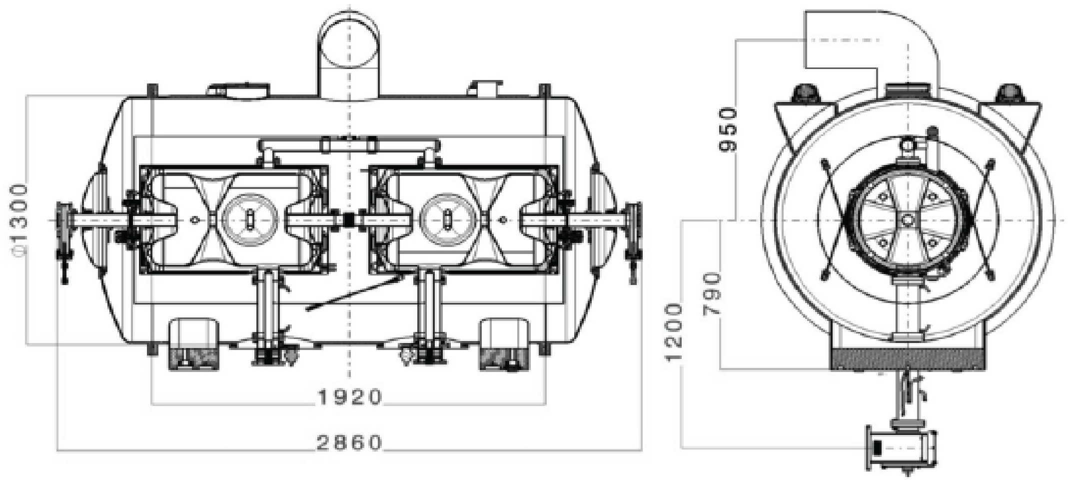
- The performance of the mechanical design: e.g. MAWP, stability, alignment;

- The safe operation of the cryomodules:

e.g. process variables, control loops, operating modes, relieving system and interlock;

- Training: e.g. to assemble, to operate.

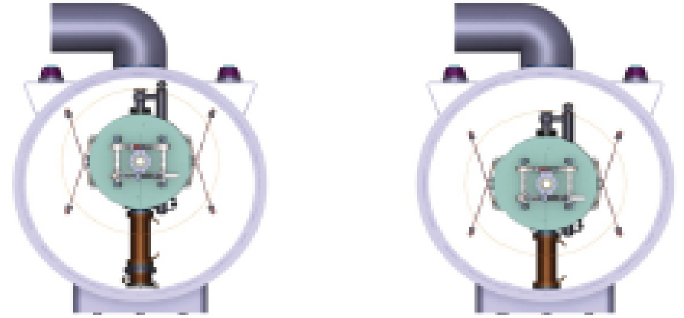
Spoke cavity string and cryomodule package



Spoke cryomodule overall dimensions

→ Technical design results:

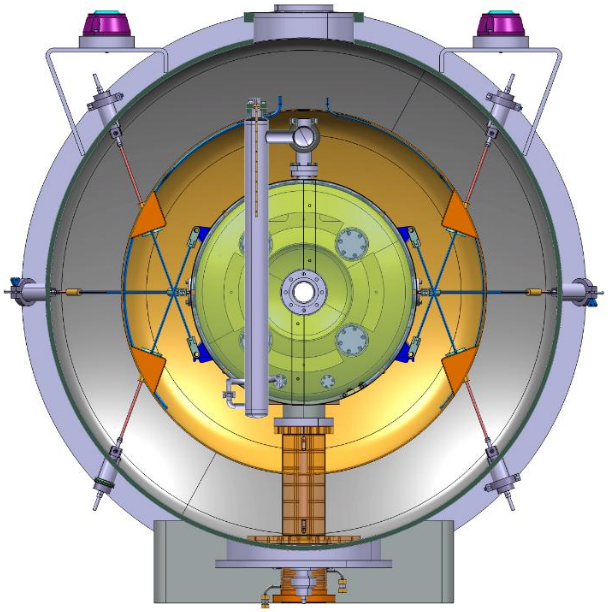
- Position coupler
- Supporting system
- Thermal shielding
- Magnetic shielding

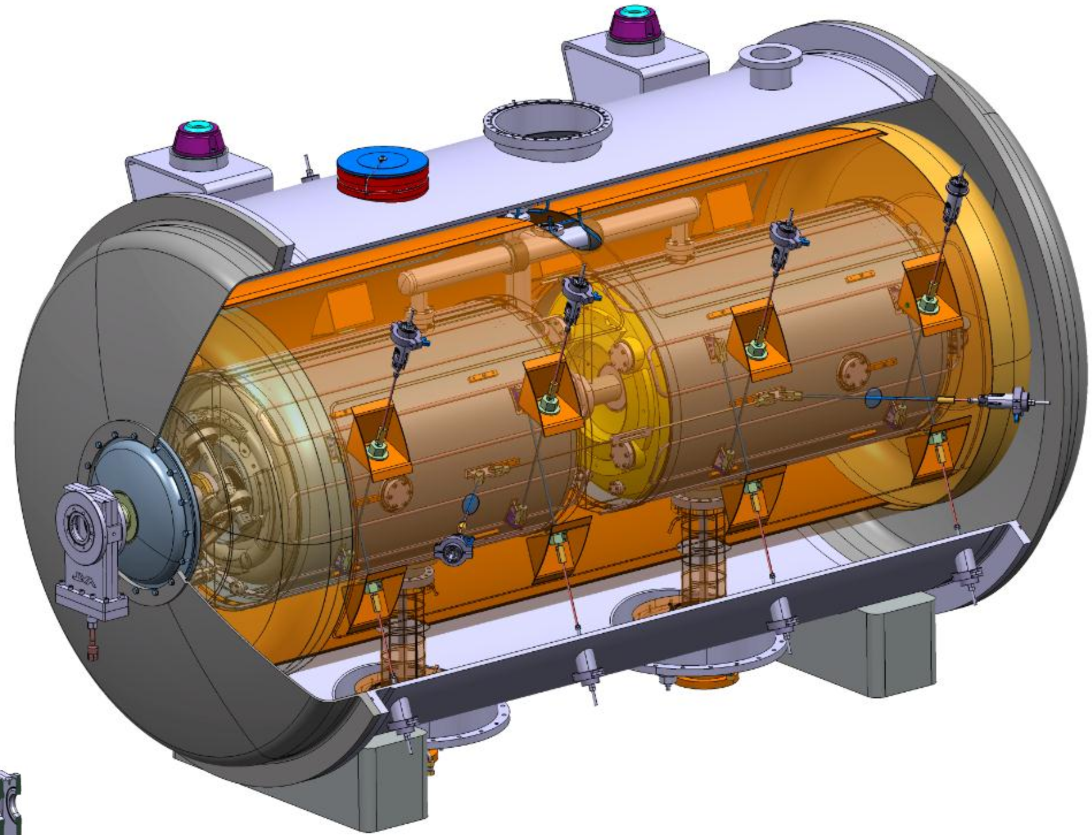


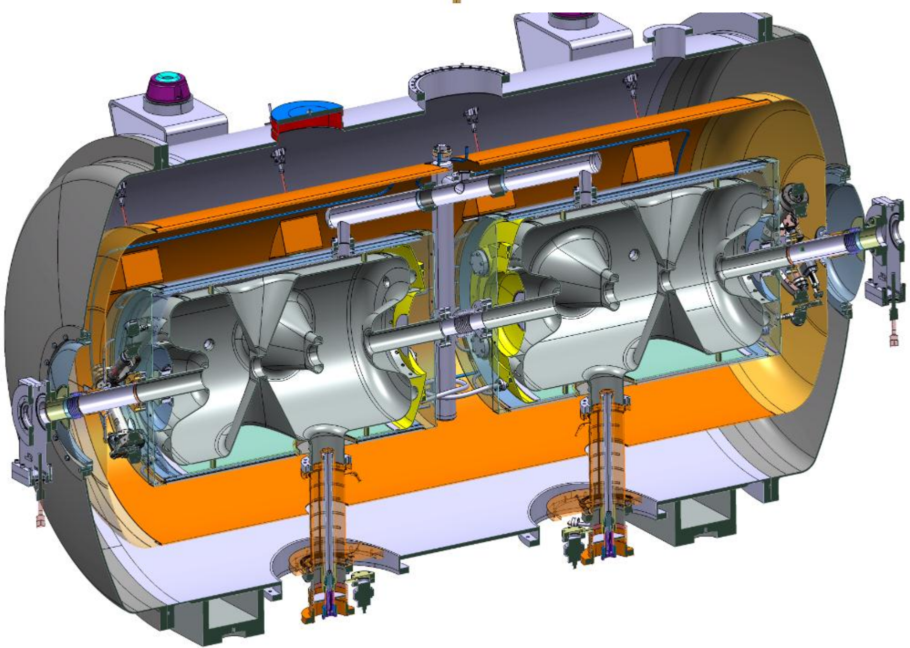
Position cavity string during cryostating step

Cavity string and its cooled magnetic shielding

Spoke cavity string and cryomodule package

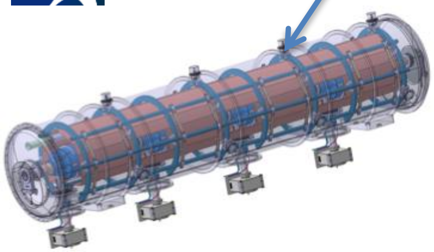


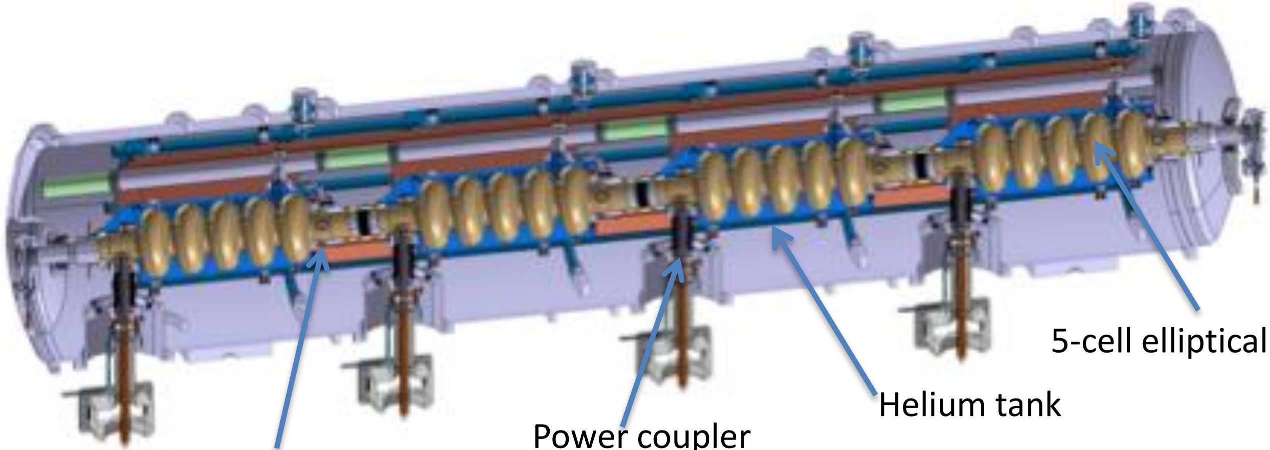


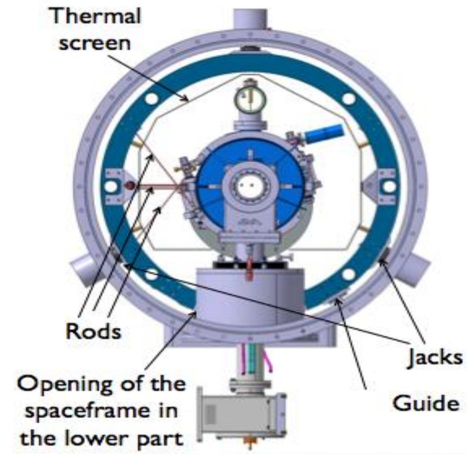


Elliptical cavity string and cryomodule package

Section	Total number of Modules	Cavity package frequency [MHz]	Cavity count per module	Cavity count per sector	Cryo-module length [m]	Sector length [m]
Spoke	14	352	2	28	~2.9	58.46
Medium-beta	15	704	4	60	~5.7	113.84
High-beta	30	704	4	120	~6.7	227.86
Total	59			208		400.16

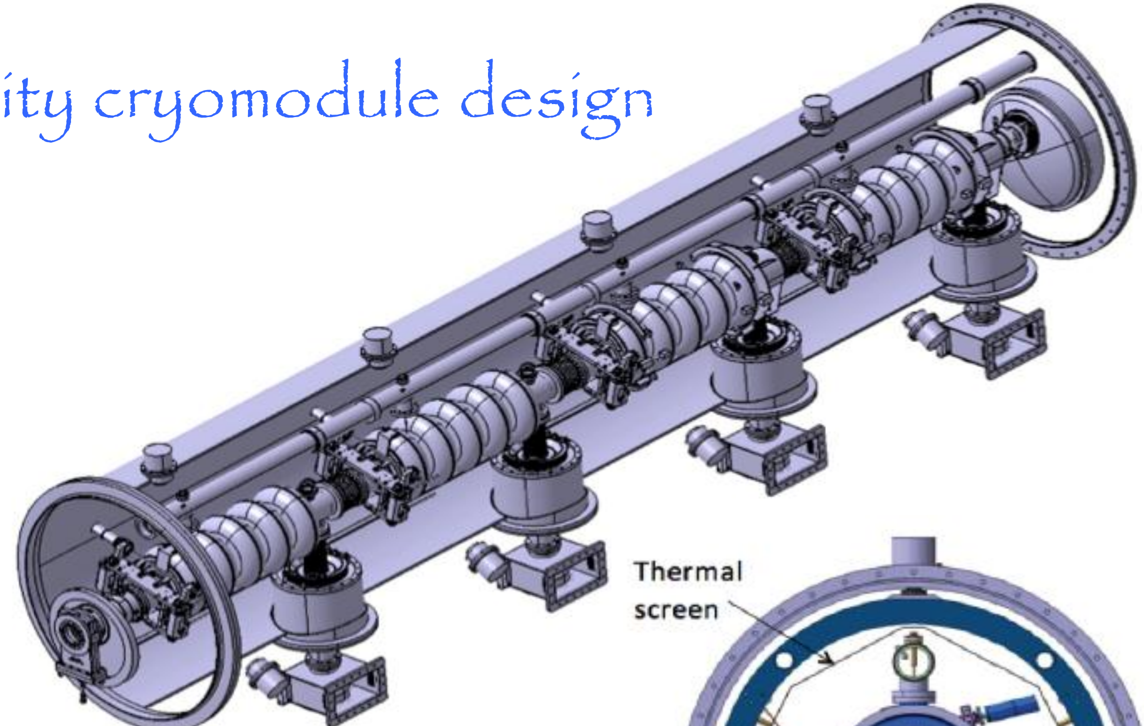






- Elliptical Cavities Cryomodule Technology Demonstrator results by the end of 2015 → start pre-series

Elliptical cavity cryomodule design



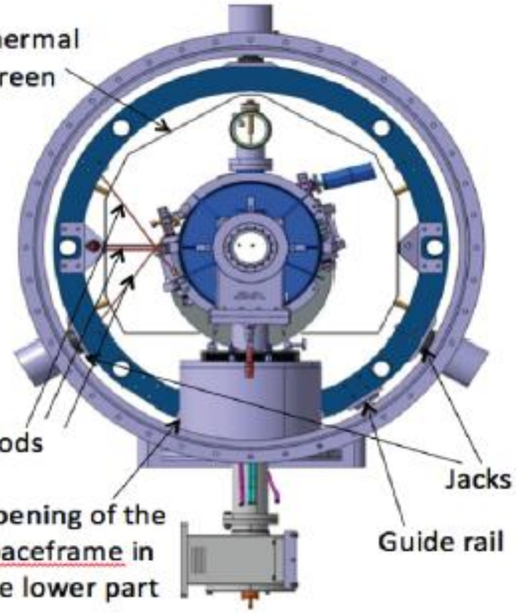
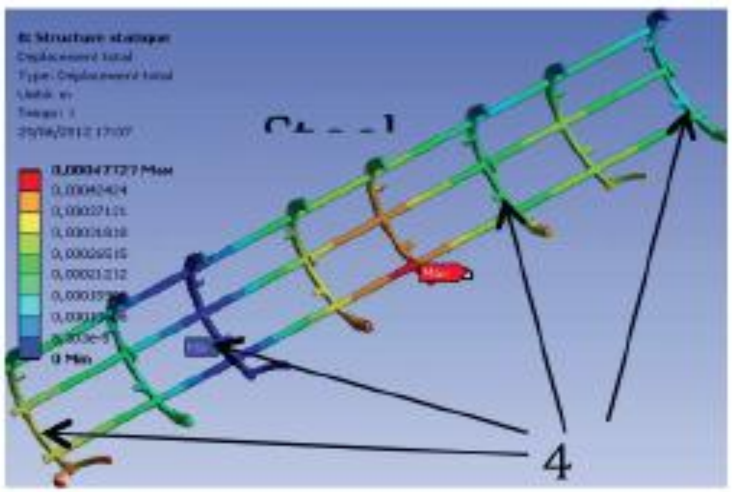
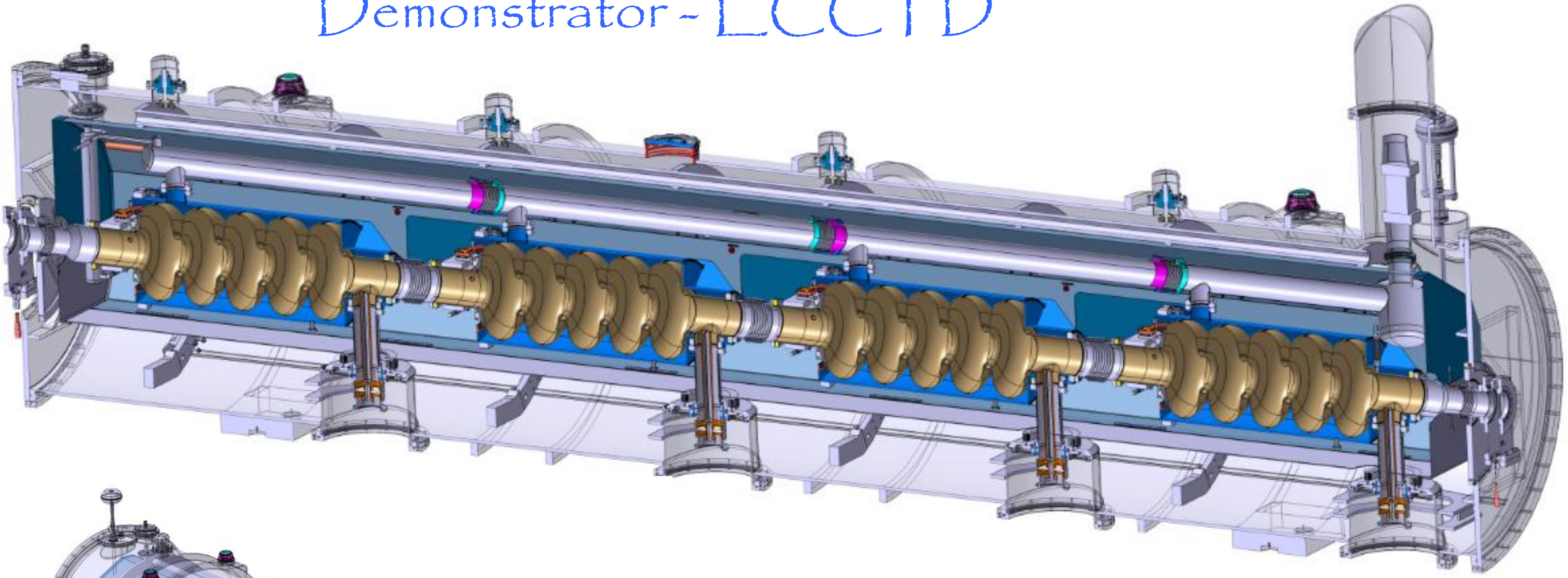


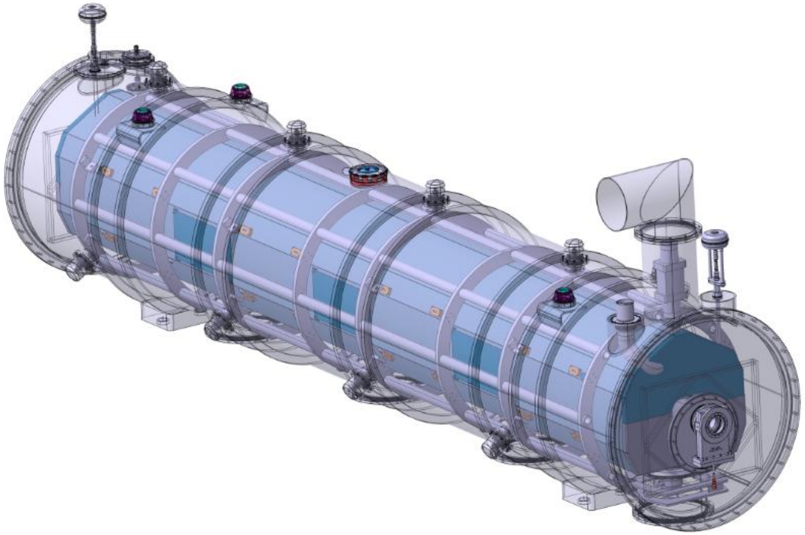
Figure 4.118: Cross section of the cryomodule



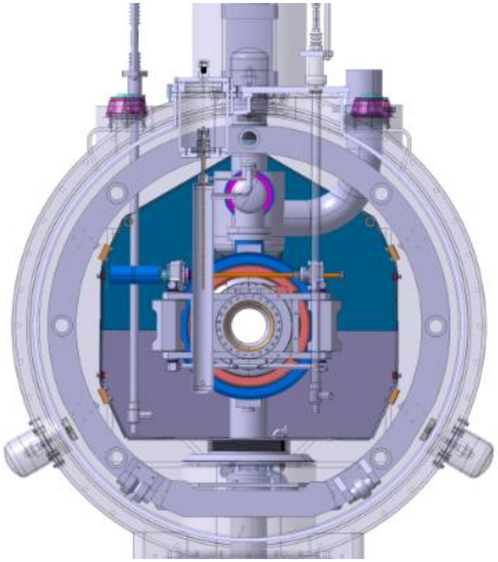
Space frame stress analysis and material choice

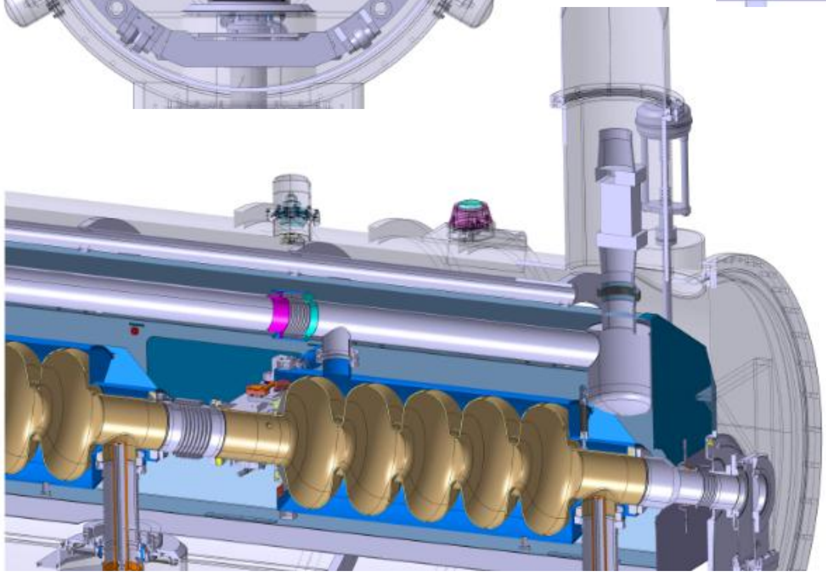
Elliptical Cavity Cryomodule Technology Demonstrator - ECCTD

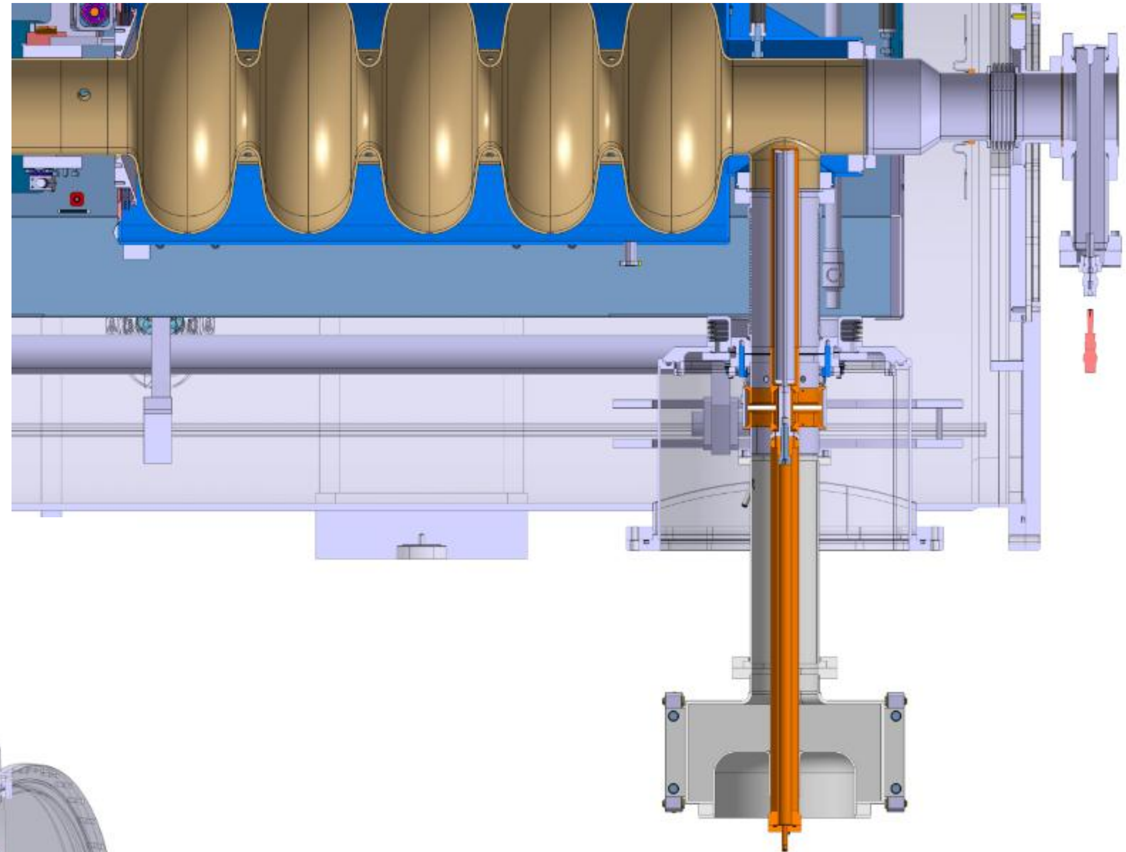




ECCTD







Conclusion

The ESS cryomodules to validate innovation applied to the next generation of accelerators

- Challenging schedule for a green field neutron source

- Effective and expertise thanks to European collaborations

EXTRA slides

Cryomodule Break Down Structure and Interface

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Cryomodule

SRF Cavity Package

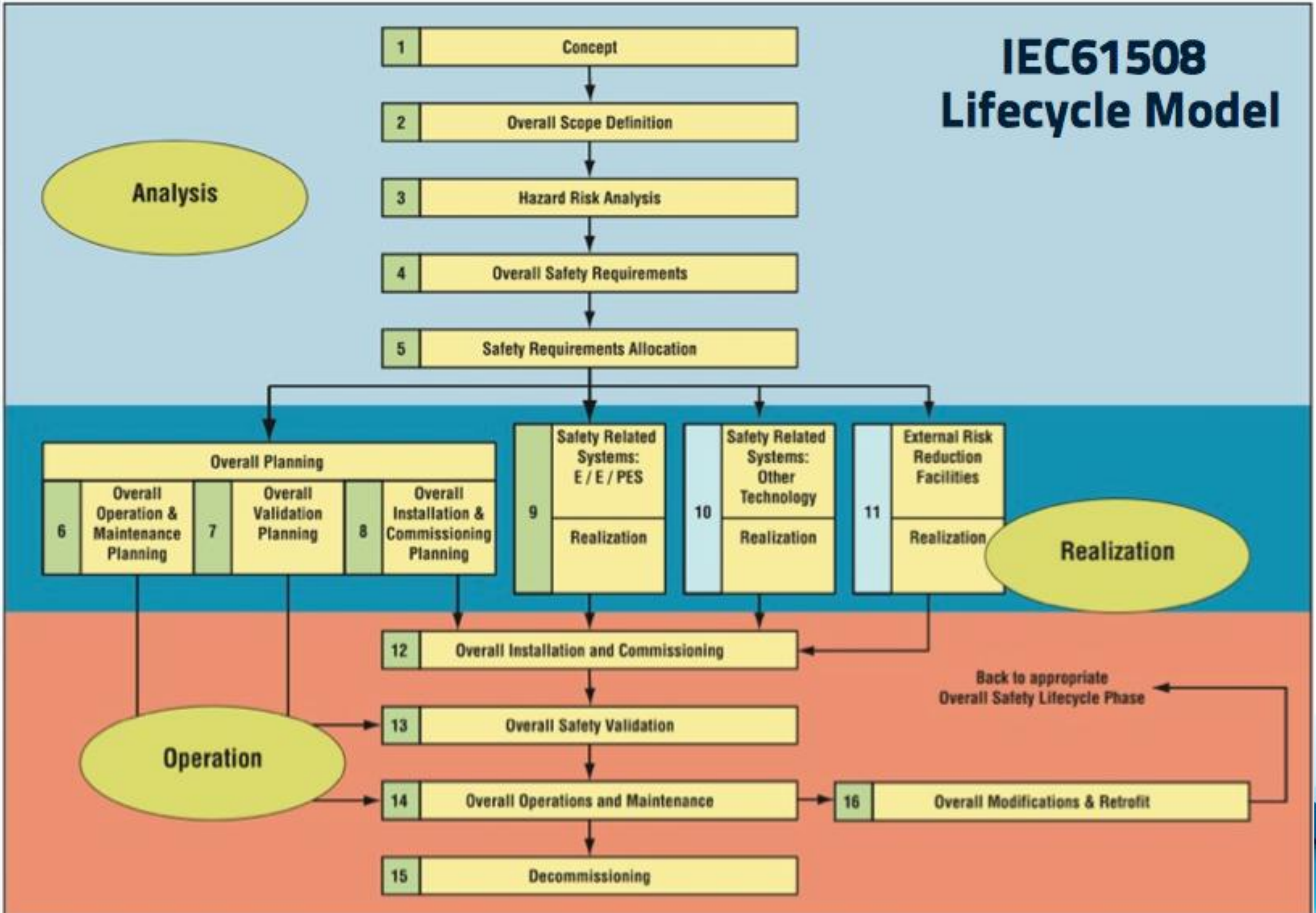
- SRF cavity (spoke or elliptical) in helium tank
- Cold tuning system
- Fundamental Power Coupler
- ~~HOM Couplers~~
- Diagnostic Inst. & Valves
- Safety equipment

(Cryomodule)

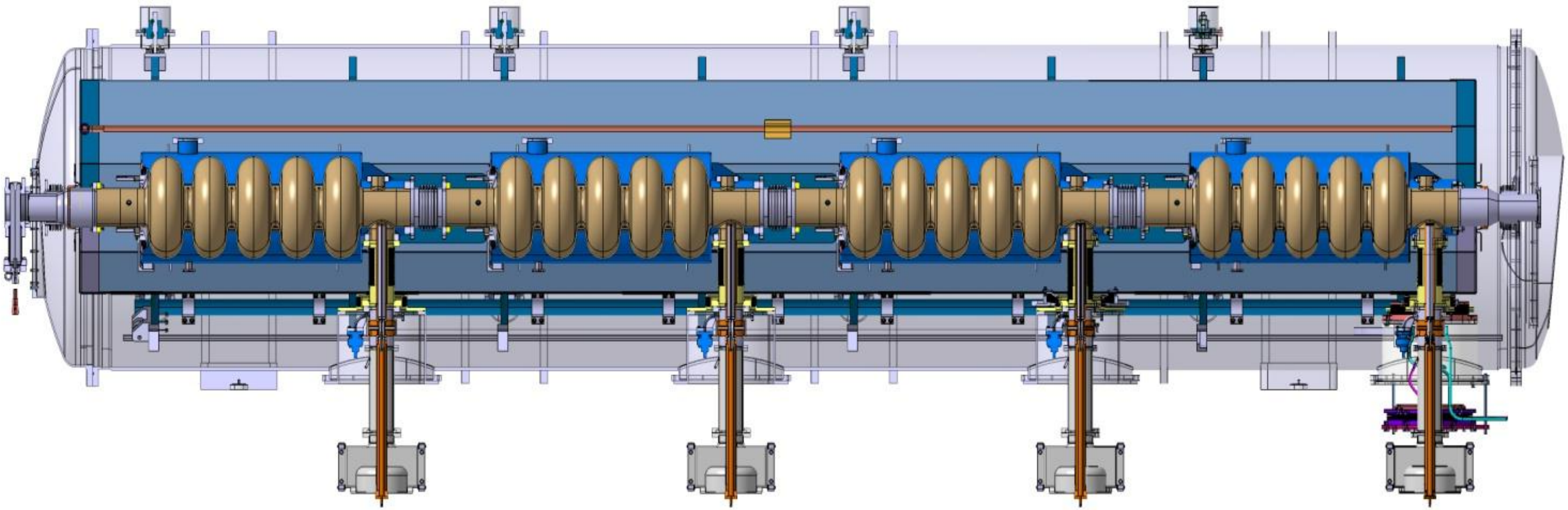
- Beam pipe
- Supporting system
- Alignment system
- Thermal shielding
- Cryo-distribution Lines
- Magnetic shielding
- Coupler cooling Sys.
- Diagnostic Inst. & Valves
- Safety equipment

Tunnel

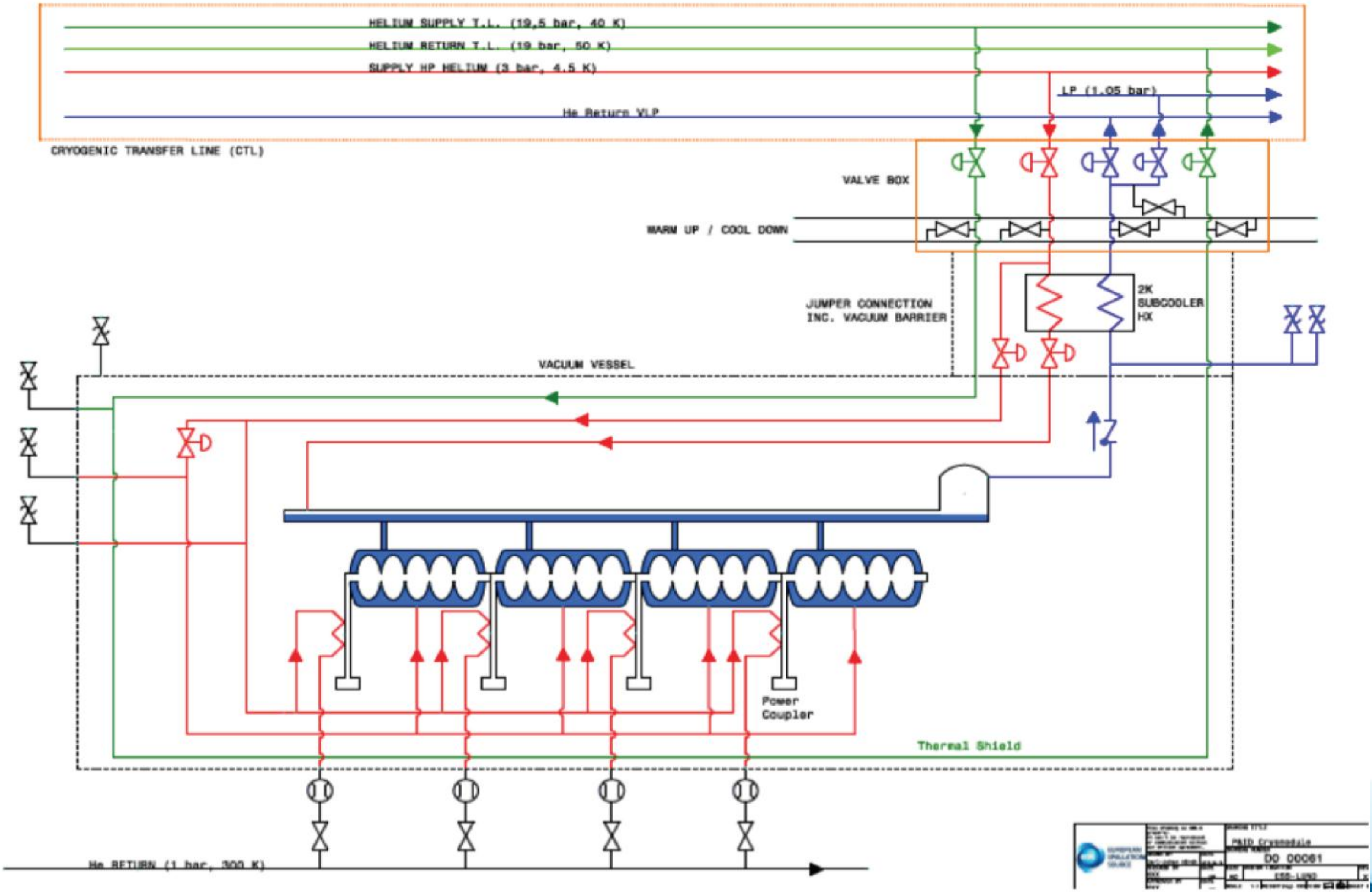
- Beam pipe
- Corrector magnet
- Vacuum station
- Instrum., BPM etc.
- Ext. supporting system
- Waveguide and RF eq.
- Control system eq.
- Cryo valve box
- Jumper connection
- Safety equipment


IEC61508
Lifecycle Model
Analysis
1 Concept
2 Overall Scope Definition
3 Hazard Risk Analysis
4 Overall Safety Requirements
5 Safety Requirements Allocation
Overall Planning
6 Overall Operation & Maintenance Planning
7 Overall Validation Planning
8 Overall Installation & Commissioning Planning
9 Safety Related Systems: E / E / PES
Realization
10 Safety Related Systems: Other Technology
Realization
11 External Risk Reduction Facilities
Realization
Realization
12 Overall Installation and Commissioning
Back to appropriate Overall Safety Lifecycle Phase
13 Overall Safety Validation
Operation
14 Overall Operations and Maintenance
16 Overall Modifications & Retrofit
15 Decommissioning

Current development



Elliptical cryomodule – flow process



WORKSHOP