EUROPEAN SPALLATION SOURCE

The ESS Cryogenics System

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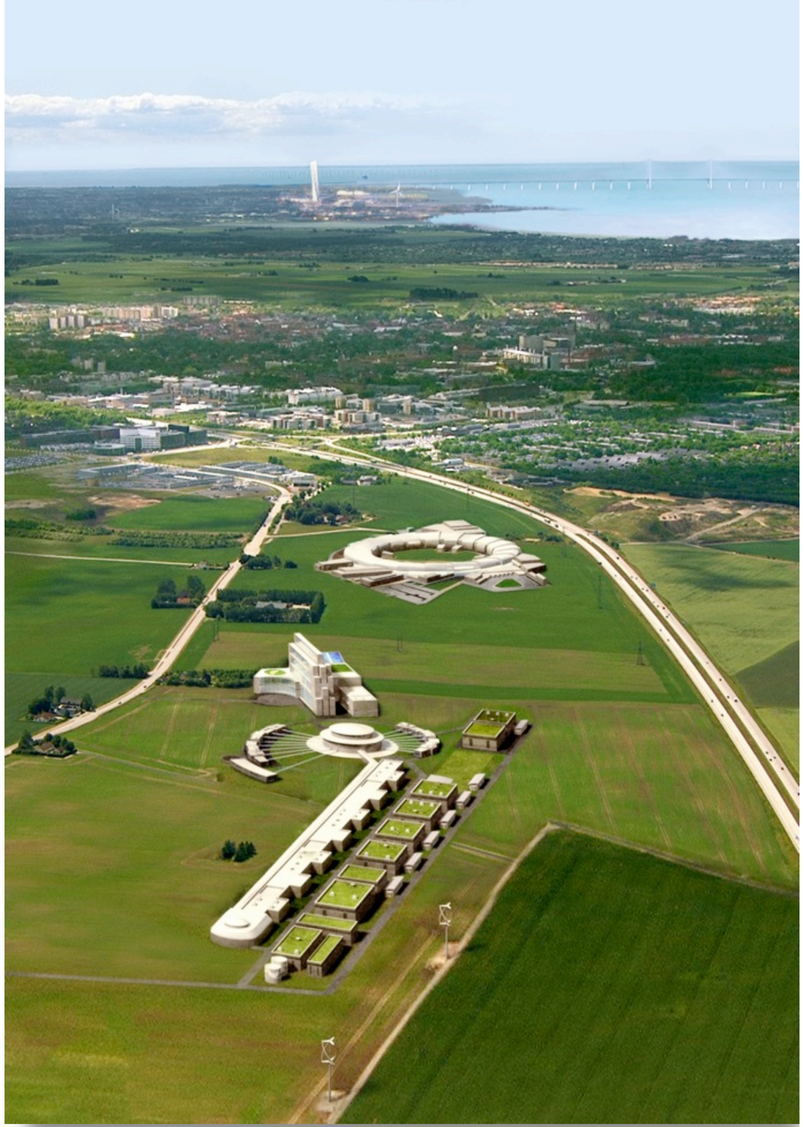
ESS Overview

- A 482.5m long, 5MW, proton linear accelerator at 2.5 GeV, 5 mA
- 2.86 ms pulses, ≈14Hz (60 ms period)
- A solid metal target
- 22 neutron instruments
- To support a 5000-strong user community
- 450 staff
- Capital Cost 1,478 M€(2008)
- Operating Cost 103 M€ p.a.
- Decommissioning Cost 344 M€
- First neutrons 2019
- Full operation 2025



LINAC layout

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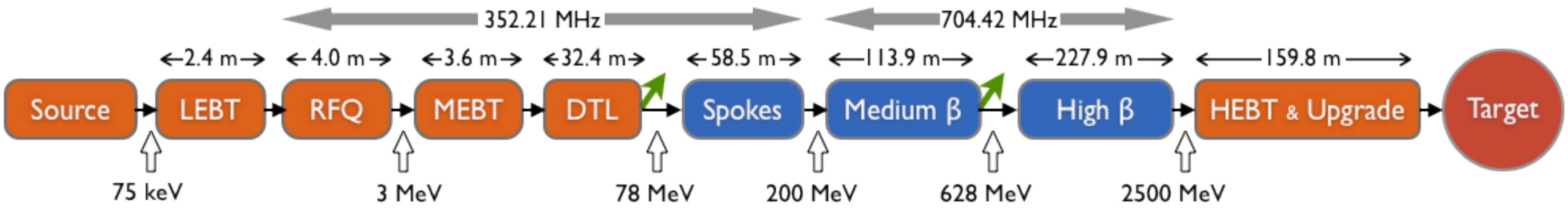
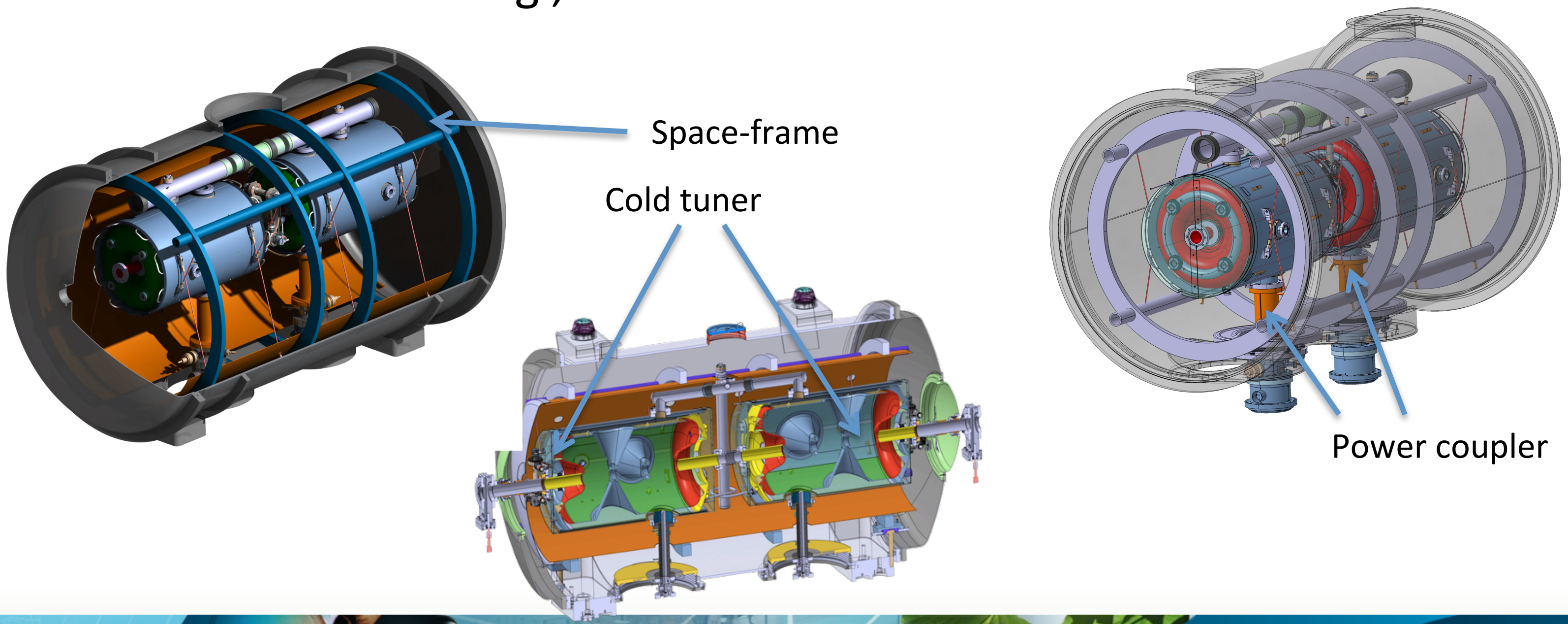


	Length [m]	Input energy [MeV]	Frequency [MHz]	Geometric β	No. of tanks or modules	No. of cells or cavities	Temp. [K]
LEBT	2.4	0.075					
RFQ	4.0	0.075	352.2		4		300
MEBT	3.6	3					
DTL	32.4	3	352.2		4	156	300
Spoke	58.5	78	352.2	0.50	14	28	≈ 2
Medium-β	113.9	200	704.4	0.67	15	60	≈ 2
High-β	227.9	628	704.4	0.92	30	120	≈ 2
HEBT	159.2	2500					

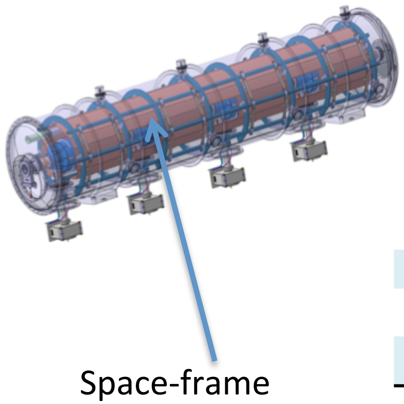
Spoke Cryomodules

The fully equipped spoke cryomodules provide operating conditions (vacuum, cryogenics) to the spoke resonators.

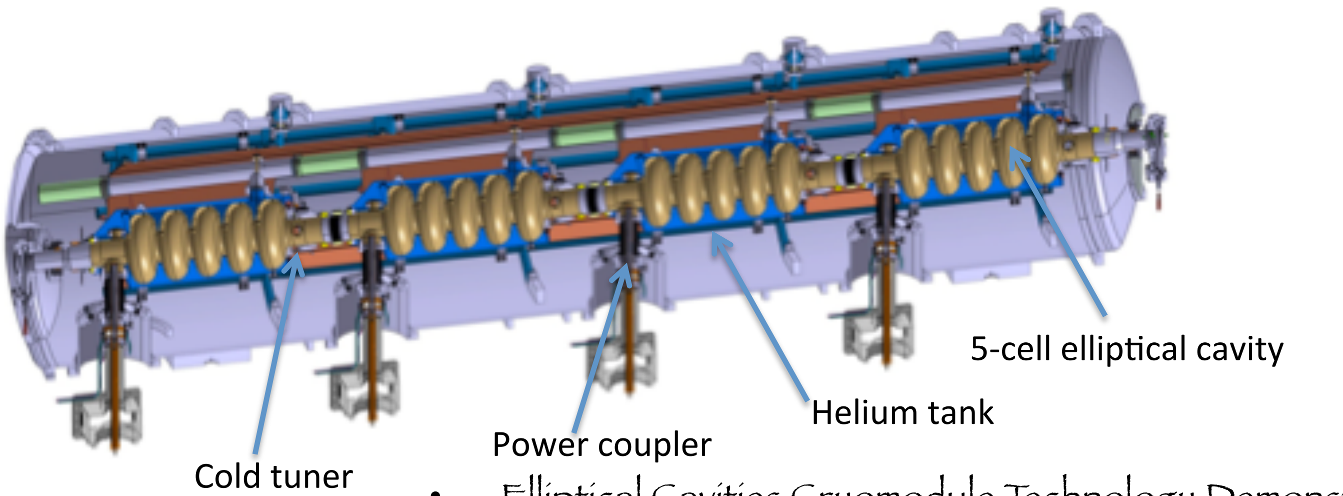
- 2 double-spoke resonators per cryomodule
- 14 cryomodules in total to cover Energy range between 79 MeV to 201 MeV
- Operation at 2 K
- Dimension : 2.9 m long , 1.3 m diameter

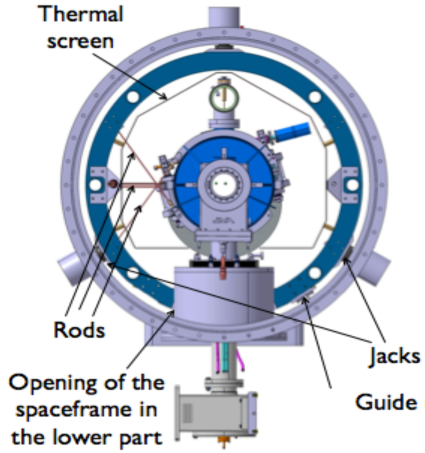


Elliptical Cryomodules



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	~ 6.7	113.84
High-beta	30	704	4	120	~ 6.7	227.86
Total	59			208		400.16



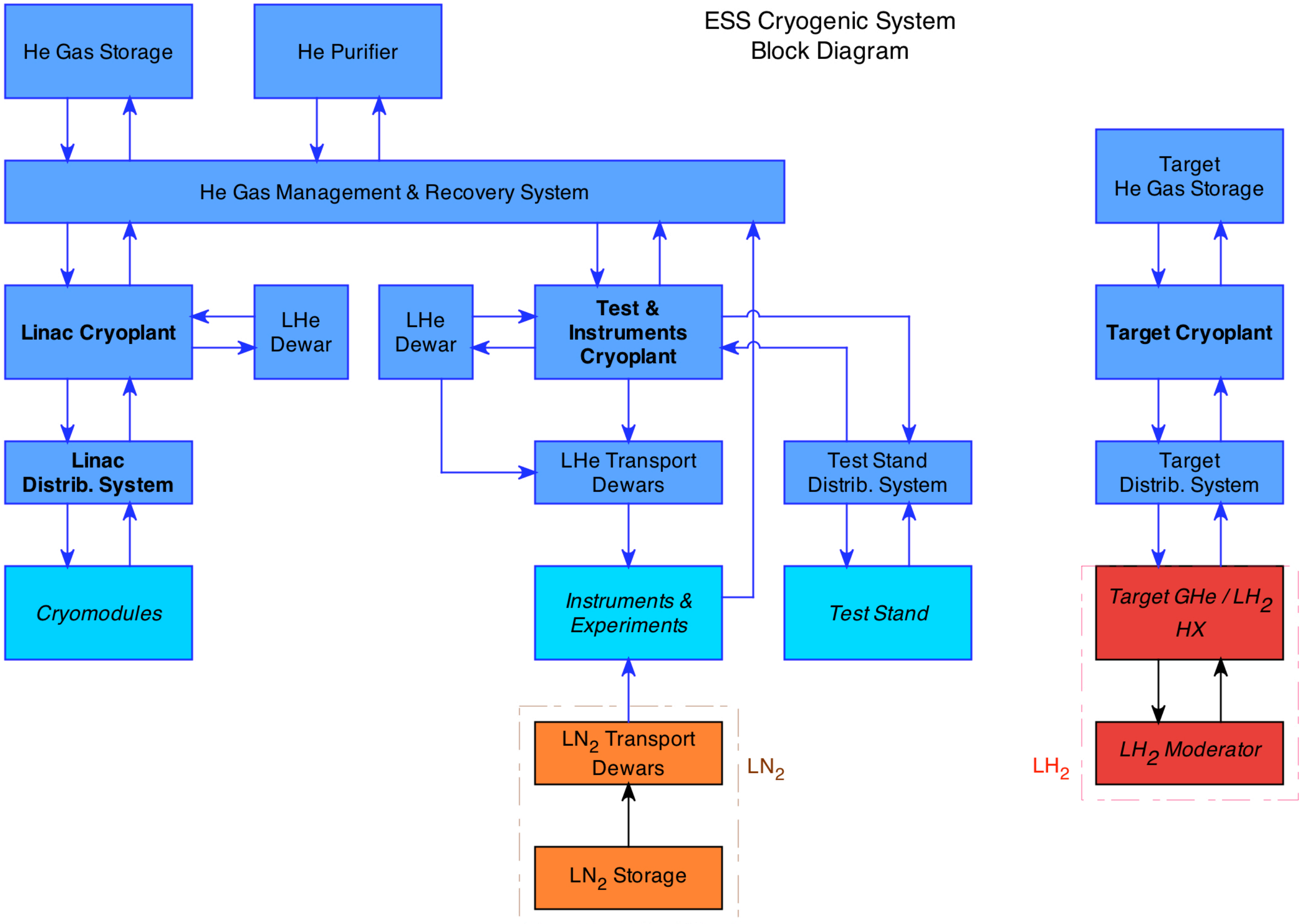


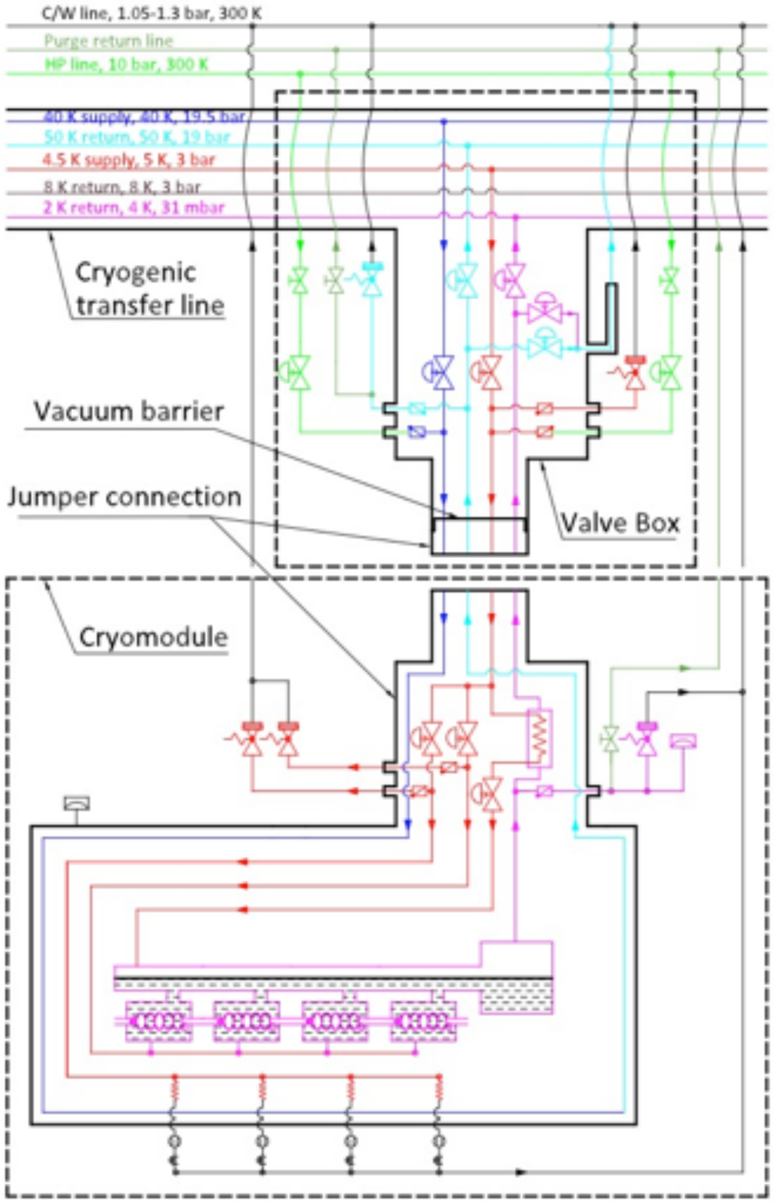
- Elliptical Cavities Cryomodule Technology Demonstrator results by the end of 2015 → start pre-series

Cryogenics Plays an Important Role at ESS

- Cooling for the cryomodules (2 K, 5 – 8 K and 40)
- Cooling for the Target LH_2 Moderator (16 K)
- Liquid Helium and Liquid Nitrogen for the Neutron Instruments
- Cooling for the cryomodule test stands (2 K, 5 – 8 K and 40 K)
- This is accomplished via 3 separate cryoplants

ESS Cryogenics System





Accelerator Cryogenics

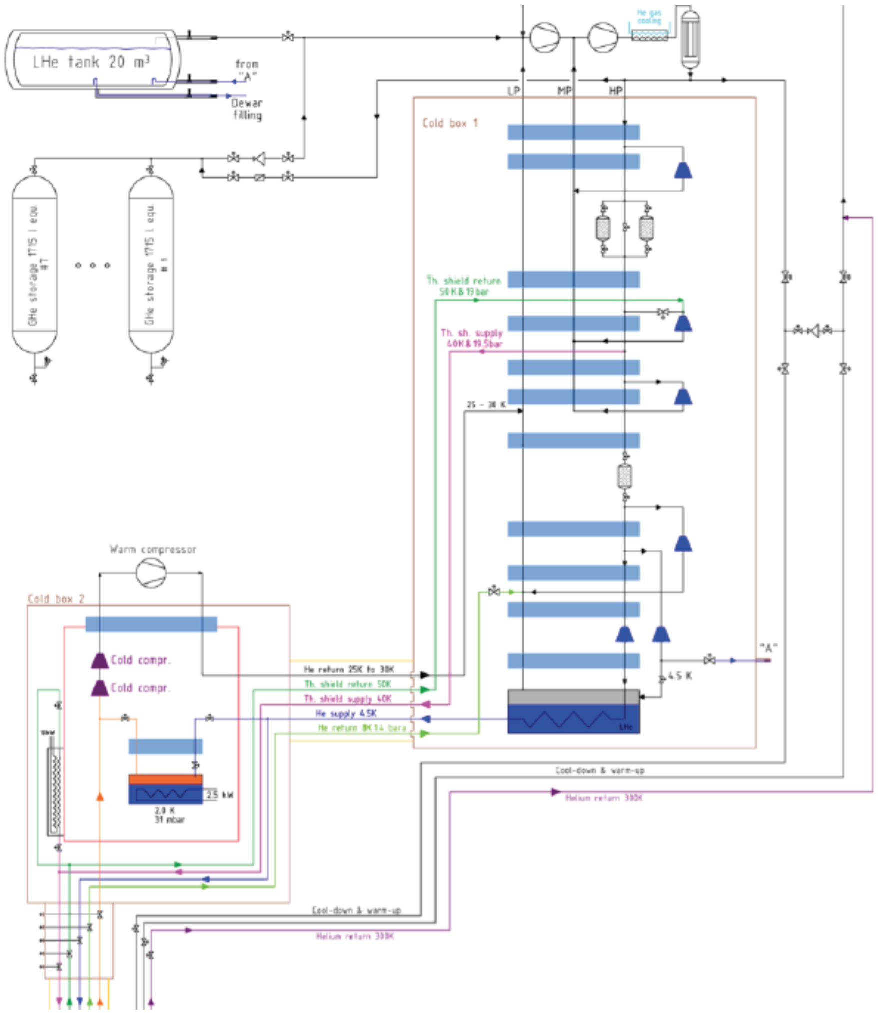
- Distribution system delivers single phase Helium at 4.5 K & 40 K
- 2 K helium produced at each cryomodule
- Sub atmospheric vapor pumped off to cryoplant
- 4.5 K – 300 K cooling of couplers

Accelerator Heat Loads

	2 K		4.5-8 K		40-50 K
	Static	Dynamic	Static	Dynamic	Static
CMs	396	1328	67.5	7.2 g/s	3889
Distribution system			1156		3983
Total predicted power	396	1328	1223	7.2 g/s	7872
Installed capacity	682	1527	2110	8.3 g/s	11769
Installed 4.5 K Equivalent	2047	4580	1582	828	841
Total installed 4.5 K Equivalent			9878		

<u>Note Large Dynamic vs. Static Loads at 2 K</u>

Accelerator Cryoplant



- Roughly 10 kW @ 4.5 K Eq. includes capacity margin
- Uses combination cold & warm compression for 2 K production (LHC approach)
- Turn down capacity & ability to recover from trips quickly are key Issues
- Industry studies will be carried out in 2013
- Plant will be ordered in 2014, ready in 2017

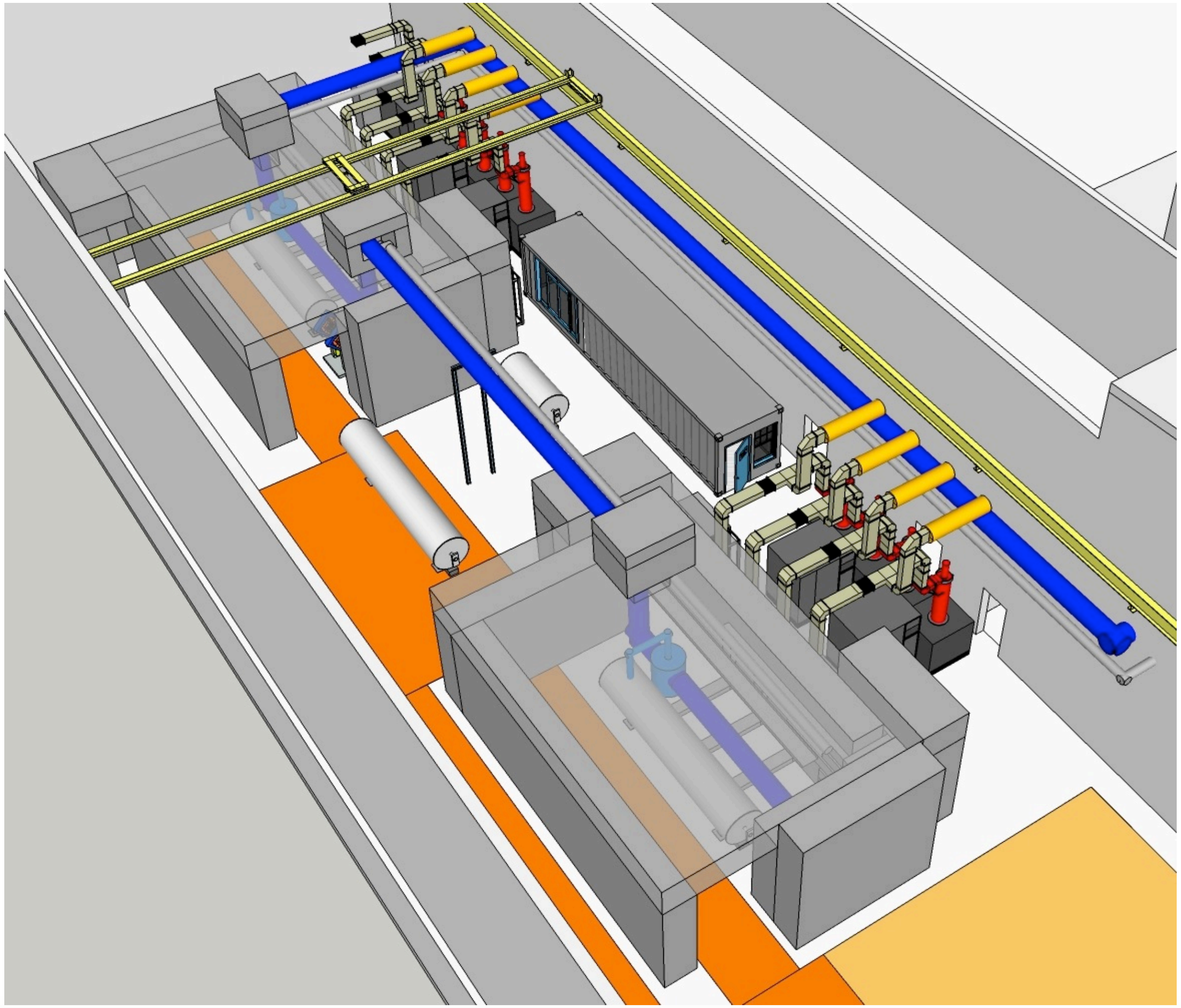
Target Cryoplant

- Provides up to 25 kW of cooling at 16 K via supercritical helium
- Hydrogen circuit is separated from Helium circuit via a heat exchanger
- Due to the possibility of tritium contamination of the helium, the helium system for the target cryoplant is completely separate from the other cryoplants
- Last plant to be ordered (2015) and commissioned (2018)

Test & Instruments Cryoplant

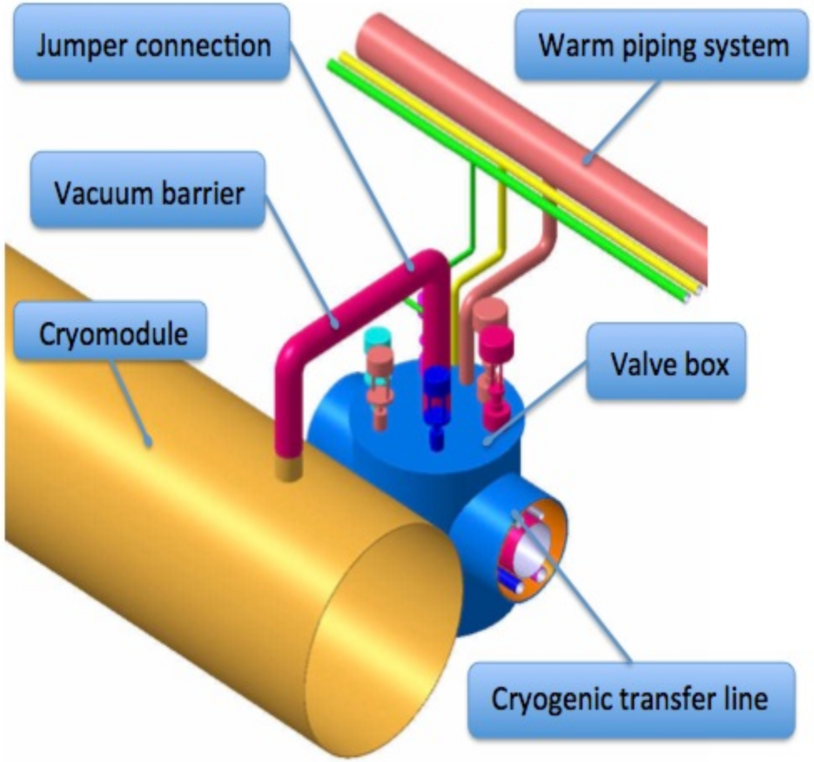
- Provides cooling for cryomodule test stands (initially) and liquid helium for the neutron instruments during ESS operations
- Liquid Helium to instruments will be supplied via portable dewars – boil off He gas will be collected, purified and reliquefied
- For the cryomodule testing plant will produce 4.5 K and 40 K Helium. 2 K Helium will be produced at the cryomodules as in the accelerator
  - Low pressure return vapor is expected to be pumped by warm vacuum pumps
- Expected capacity is ~ 500 W at 4.5 K, 200 W at 40 K
  - This will be more than sufficient to proved 50 l/h of liquid during ESS operations
- First plant to be ordered in 2014 and required by 2016

ESS Test Stands

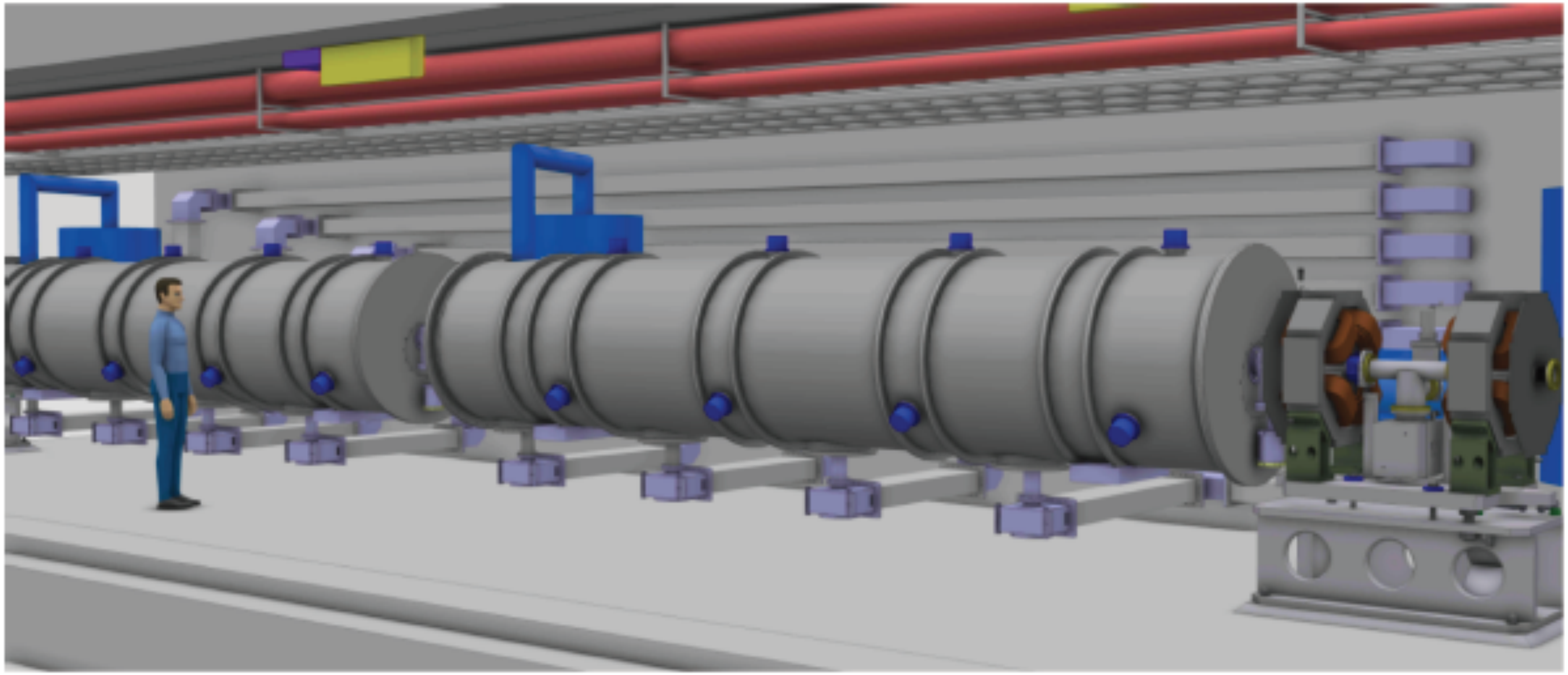


Distribution System

- Allows warm up and cool down of one or more cryomodules
  w/o affecting remaining cryomodules
- Connection between distribution line & cryomodule is done via fixed connections and not bayonets
  - Lower heat leak and cost
- Operating Modes defined
- Initial P&ID complete
- Sizing & conceptual design is well underway
- Separate isolation vacuums in the distribution lines and cryomodules



View of ESS Tunnel



Gas Management, Purification & Storage

- Provides a central system for storage, purification and gas handling for both the Accelerator and Test & Instruments cryoplants
- Goal is to ensure all helium used is recovered, cleaned and reliquefied
- Estimated liquid helium inventory in the accelerator is 12,000 l
- Planned storage
  - Gas at 2 MPa – 12,000 l (LHe equivalent)
    - "dirty" & "clean" storage likely
  - 20,000 l LHe storage - for second fill and loss compensation
  - 5,000 l LHe storage for Instruments supply backup
  - LN_2 storage requirements are TBD

Gas Management, Purification & Storage

- System will include a low temperature (LN_2) system for purification of Helium gas
- System will include instrumentation for the monitoring of He purity
- Significant engineering & design remains to be done
- This system is important to the success of the rest of the ESS cryogenics facility
- Early parts of the system including the purifier need to arrive with the T&I cryoplant

Controls

- For the 3 cryoplants: controls and programming including the PLC will be carried out by the plant vendors
- Integration of the Cryoplant PLCs to the the Integrated Control System (ICS) will be done via EPICS using ESS controls staff. This group will also provide data logging, alarms, HMI etc.
- For the Distribution System & Gas storage System all controls (including at the PLC level) will be done by ESS Controls experts

Reliability & Availability

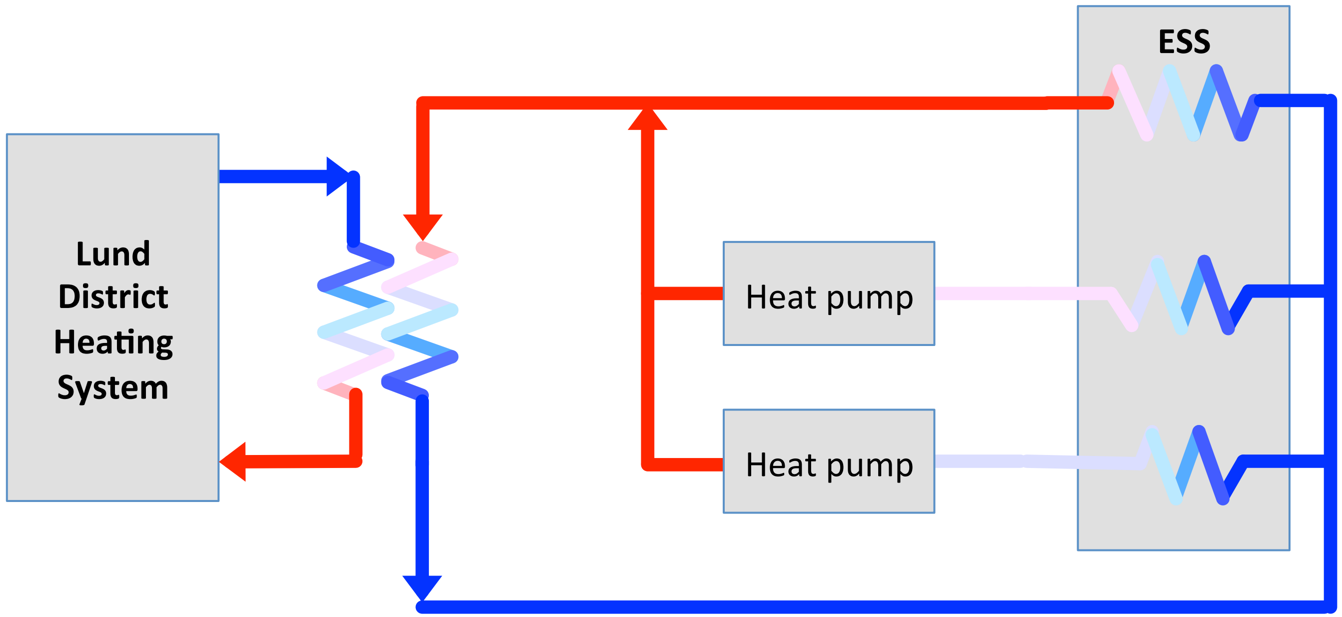
- ESS has very high (95%) availability requirements
- Meeting these needs with the cryogenic system is possible with sufficient work and planning
  - Backup power for controls and instrument air systems
  - Backup Helium compressors where appropriate
  - Strict attention to oil removal & helium purity
  - Backup LHe storage for instruments and rapid refill
  - Design of plants to optimize recovery from trips (LHC experience)
  - Failure mode studies (underway)

Sustainability

- ESS is dedicated to developing a sustainable laboratory. The rubric is: responsible, recoverable and renewable
  – Responsible: minimize energy usage
    - Choices in cryogenic design, plant efficiency & turn down capability
  – Recoverable: Waste Heat from compressors used in Lund District Heating system
  – Renewable – use renewable energy sources as possible

Recyclable

Simplified heat flow between ESS and Lund District Heating system



Summary

- Cryogenics is a key enabling technology of the ESS
- Solutions are within the current state of the art but require custom designs and significant attention to detail – turn down capability & recovery from trips
- Challenges include: meeting availability requirements, incorporating sustainability and an aggressive schedule
- There is much work to be done and significant opportunities for outside collaborations