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EUROPEAN SPALLATION SOURCE

Cryogenics at The European Spallation Source

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W. Hees, J. Jurns, X.L. Wang

July 2014

Outline

EUROPEAN SPALLATION SOURCE

- Introduction to ESS
- Applications of Cryogenics at ESS
  - Accelerator Cryoplant
  - Cryogenic Distribution System
  - Target Moderator Cryoplant
  - Test and Instruments Cryoplant
- He Recovery and Storage
- Energy Recovery
- Opportunities for In-Kind Contributions
- Summary

Introduction to ESS

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The goal of ESS is to provide a spallation based neutron source significantly more powerful than existing sources: 30 times brighter than ILL and 5 times more powerful than SNS

This facility will enable neutron based research in a wide range of fields including: materials science, condensed matter and biomedical studies

Why Neutrons?
Neutrons and x-rays are complementary - neutrons…

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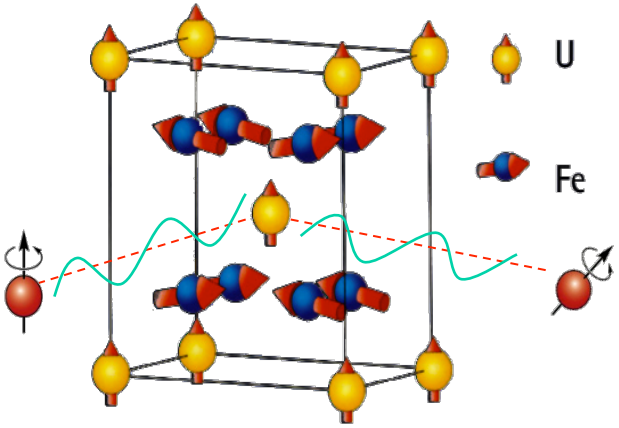
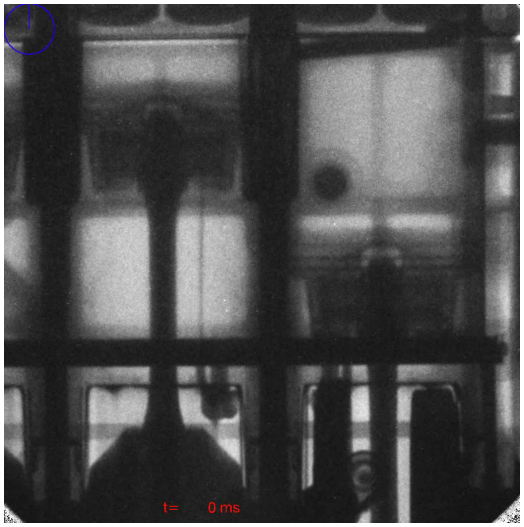
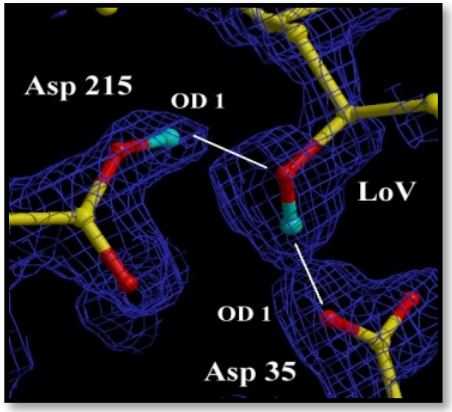


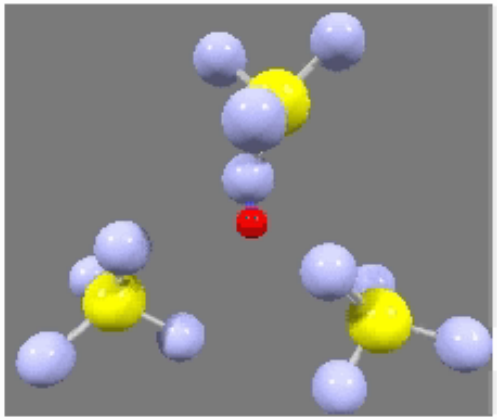
..see magnetic atoms



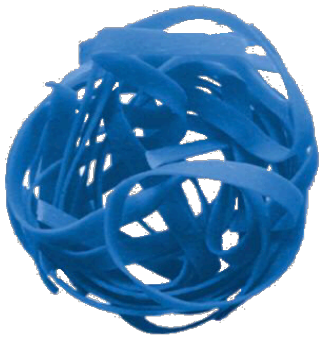
..see inside materials

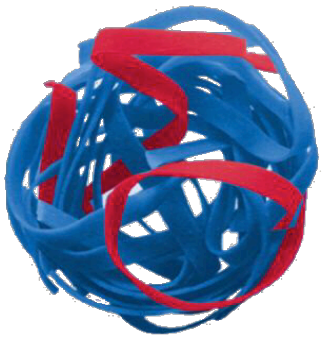


..see light atoms



..see atoms move

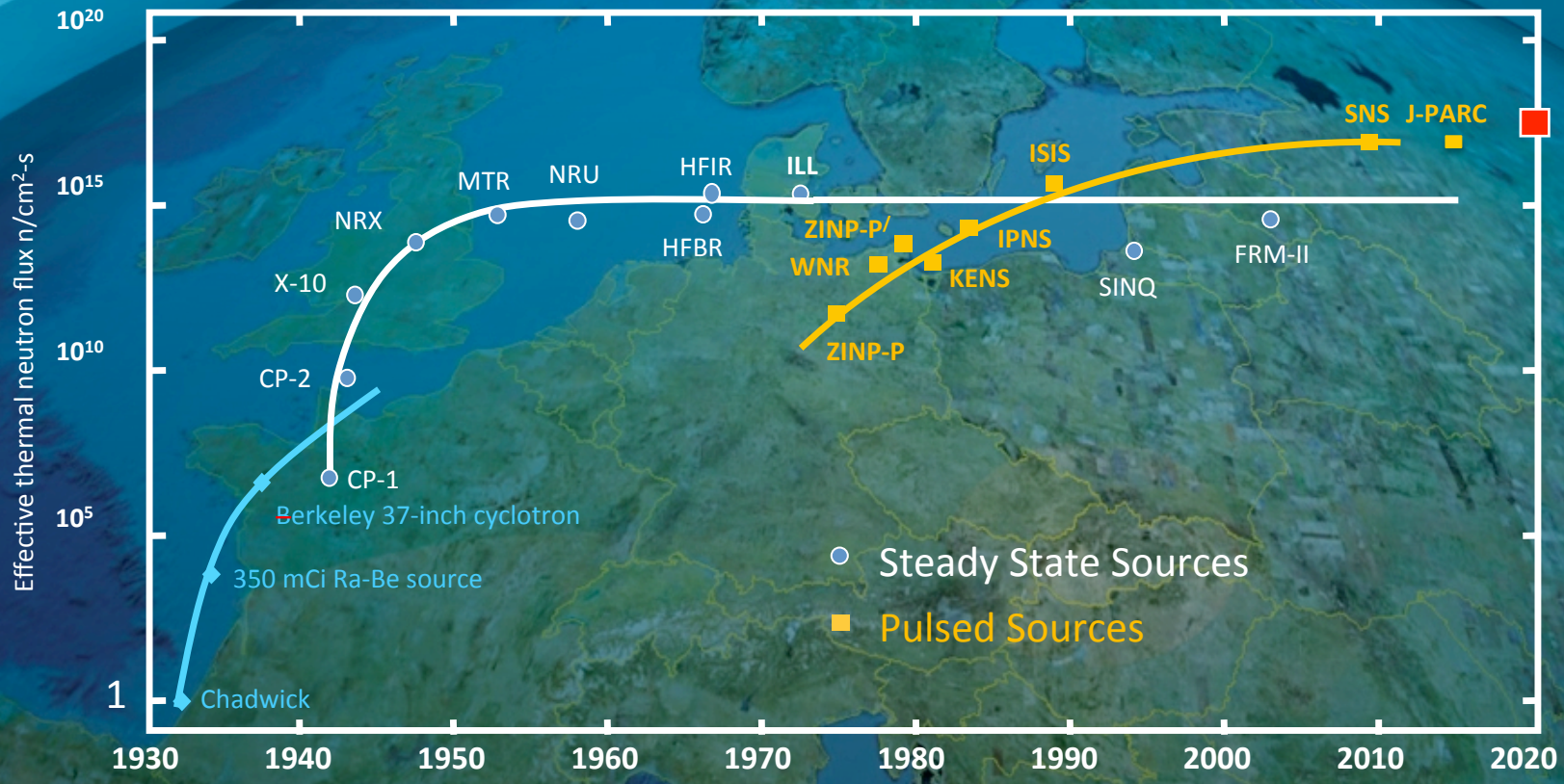




..see isotopes

Courtesy of Ian S. Anderson

ESS - Bridging the neutron gap



(Updated from *Neutron Scattering*, K. Skold and D. L. Price, eds., Academic Press, 1986)

ESS Overview

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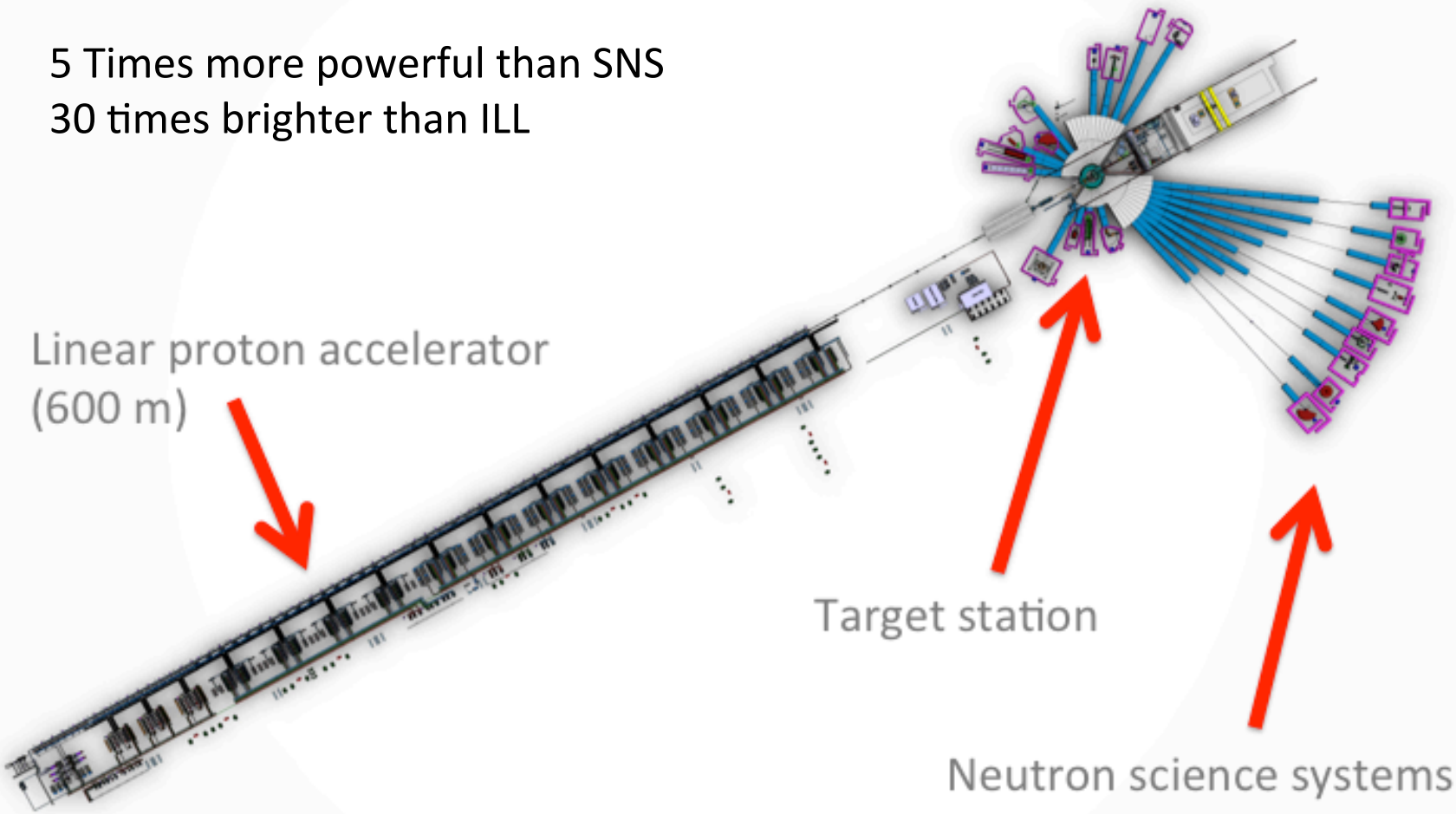
5 Times more powerful than SNS
30 times brighter than ILL



A European Science Project

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Sweden,
Denmark and Norway:
50% of construction and
20% of operations costs

European partners
pay the rest

The view of the Southwest in 2025

EUROPEAN SPALLATION SOURCE

- MAX IV – a national research facility, under construction, opens up in 2016
- Science City – a new part of town
- ESS – an international research facility

ESS Linac

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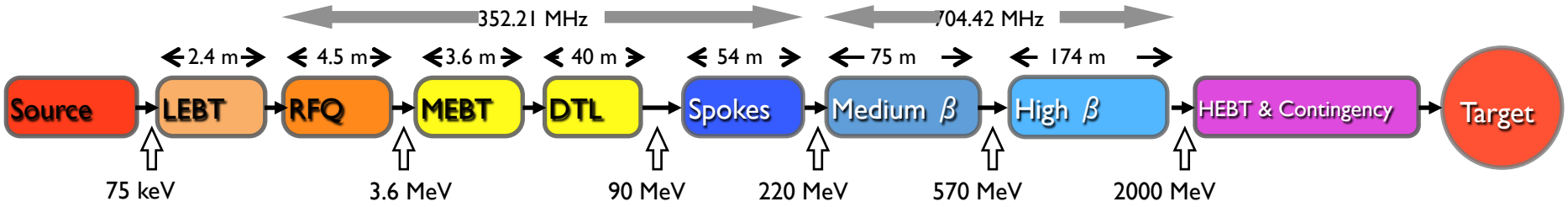
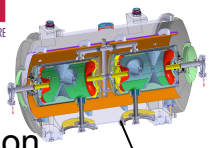


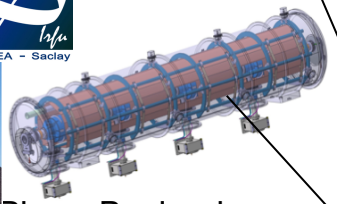
	Energy (MeV)	No. of Modules	No. of Cavities	βg	Temp (K)	Cryo Length (m)
Source	0.075	1	0	–	~300	–
LEBT	0.075	–	0	–	~300	–
RFQ	3.6	1	1	–	~300	–
MEBT	3.6	–	3	–	~300	–
DTL	90	5	5	–	~300	–
Spoke	220	13	2 (2S) × 13	0.5 β_{opt}	~2	4.14
Medium β	570	9	4 (6C) × 9	0.67	~2	8.28
High β	2000	21	4 (5C) × 21	0.86	~2	8.28
HEBT	2000	–	0	–	~300	–

Prototyping the ESS accelerator

Sebastien Bousson

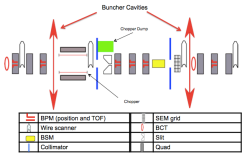


Pierre Bosland

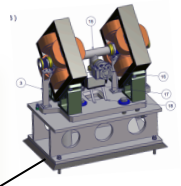


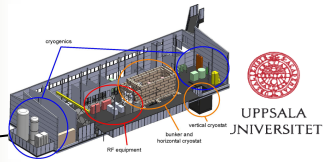
CERN

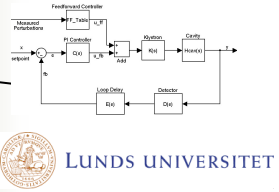
Roger Barlow

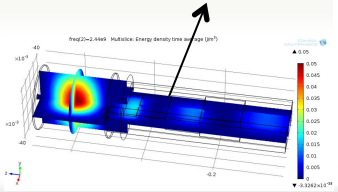


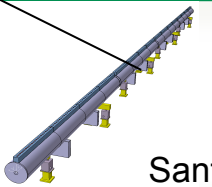
Ibon Bustinduy











Santo Gammino

Søren Pape Møller

Roger Ruber

Anders J Johansson

The National Center for Nuclear Research, Swierk

Applications of Cryogenics at ESS

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- Cooling for the cryomodules (2 K, 4.5 – 300 K and 40 K)
- Cooling for the Target supercritical H_2 Moderator (16.5 K)
- Liquid Helium and Liquid Nitrogen for the Neutron Instruments
- Cooling for the cryomodule test stand (2 K, 4.5 – 300 K and 40 K)
- This is accomplished via 3 separate cryoplants

Accelerator Cryogenics

EUROPEAN SPALLATION SOURCE

- Bulk of acceleration is carried out via 3 classes of SRF cavities: Spoke, Medium (β = 0.67) Beta Elliptical and High (β = 0.86) Beta Elliptical
- No superconducting magnets in the accelerator. There are some in the instruments
- Cavities operate at 2 K with a 40 – 50 K thermal shield
- Inner power coupler cooling from 4.2 K to 300 K
- Accelerator lattice permits an 14 additional cryomodules to compensate for lower than expected cryomodule gradients (Stage 2)

Elliptical Cryomodule Components

EUROPEAN SPALLATION SOURCE

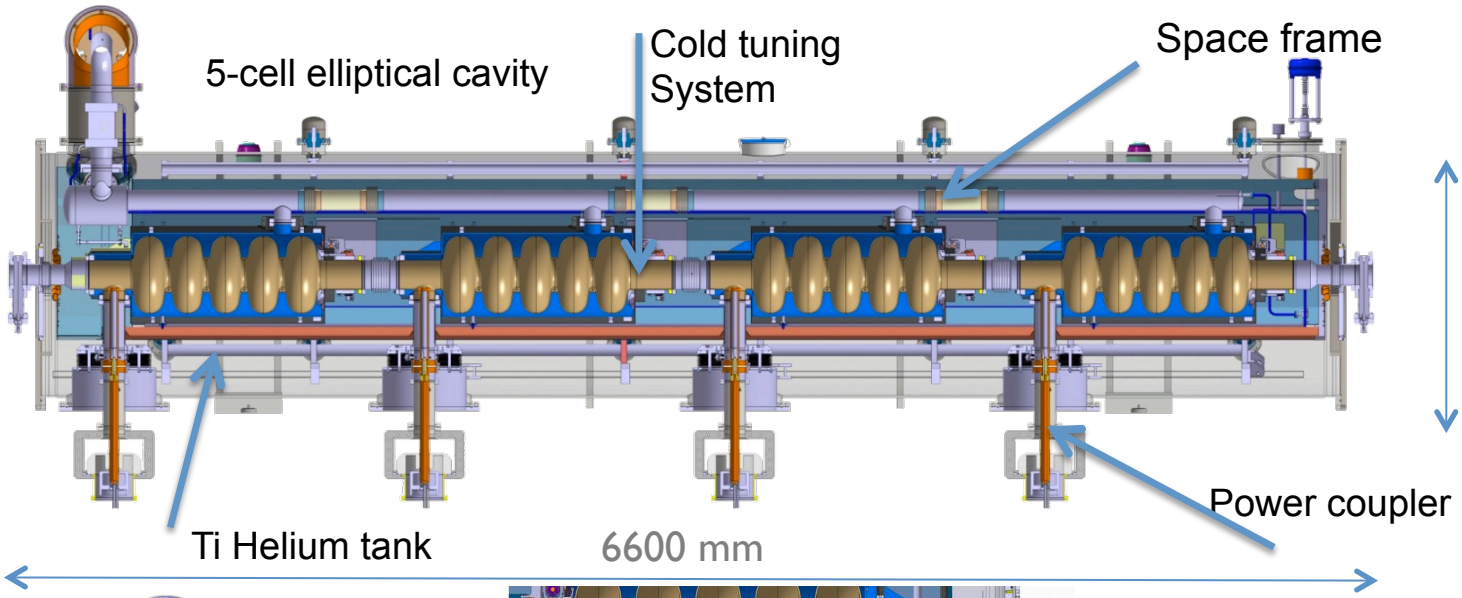
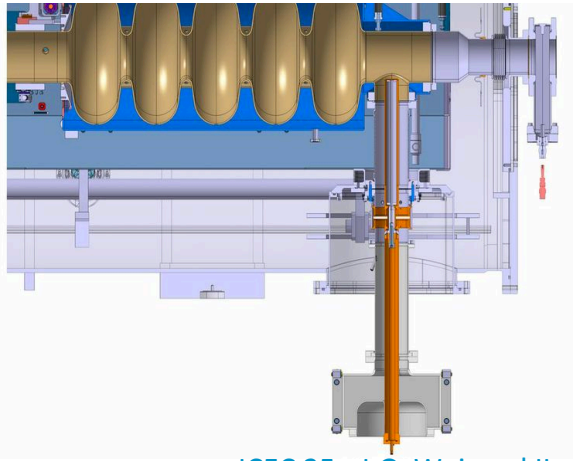
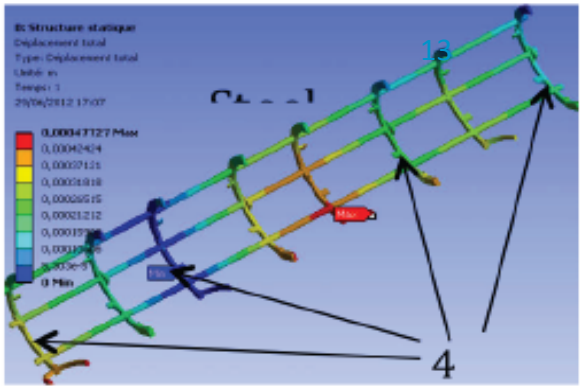


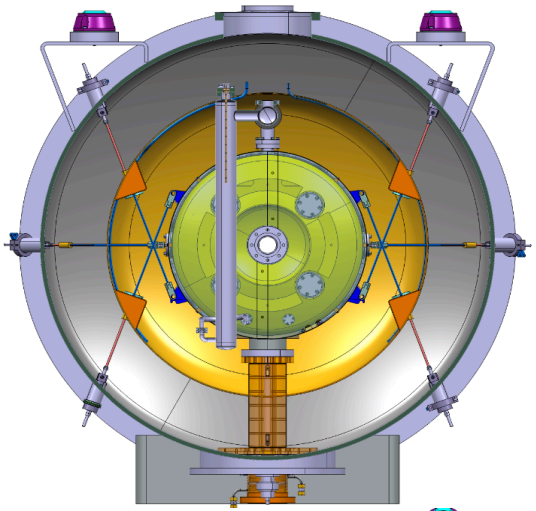
Figure 4.120: Helium vessel with hanging rod



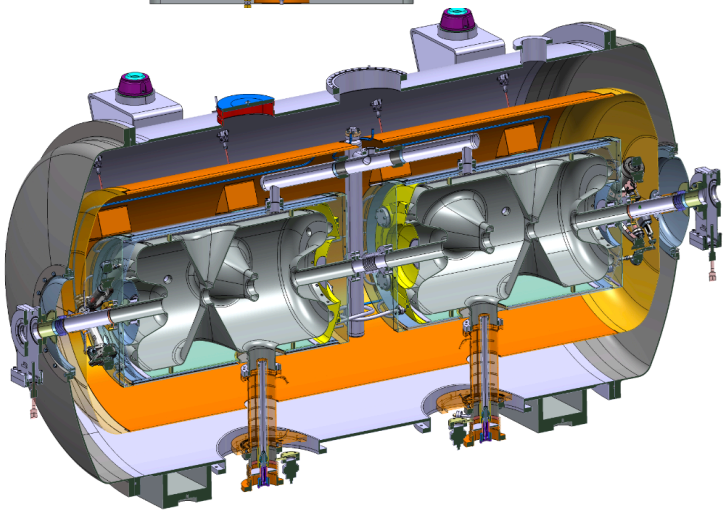


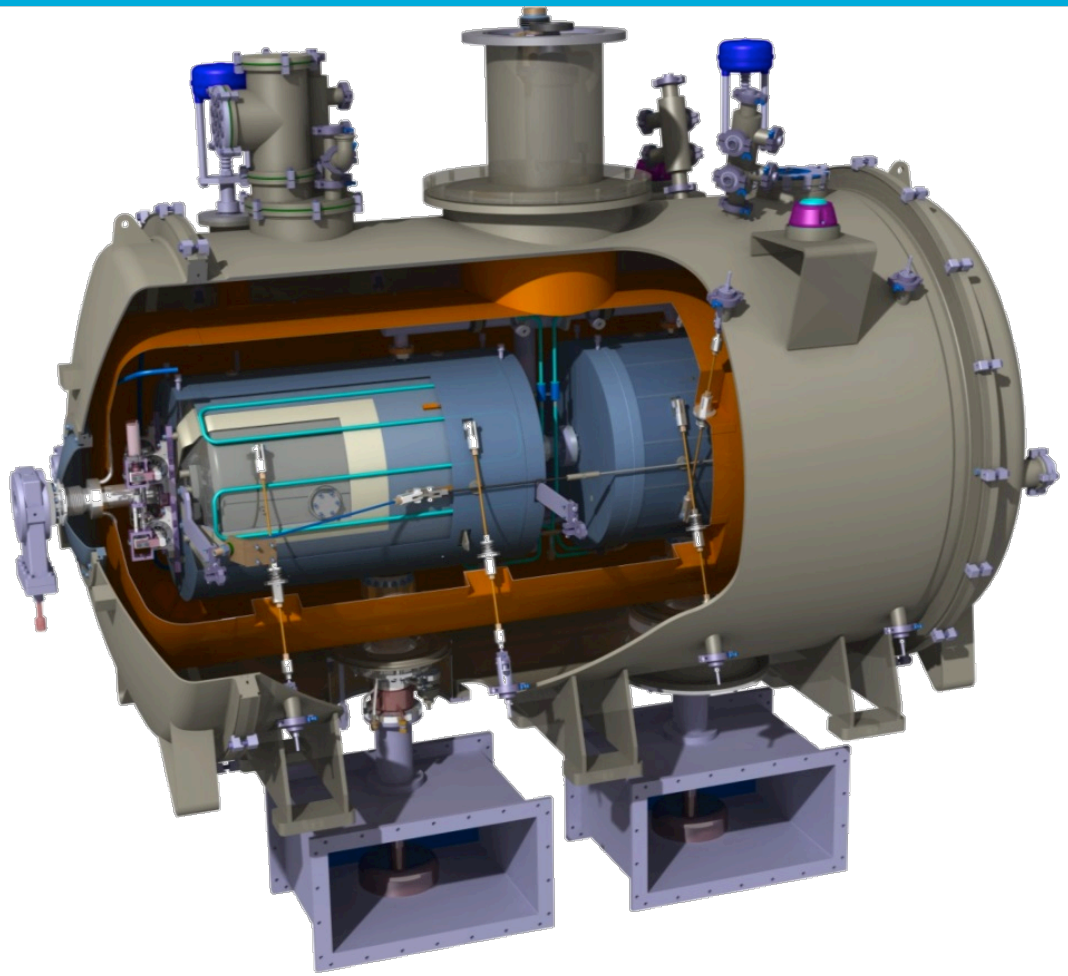
Spoke cavity string and cryomodule package

EUROPEAN SPALLATION SOURCE



Diameter
1350 mm





2900 mm

Cryomodule Heat Load Distribution

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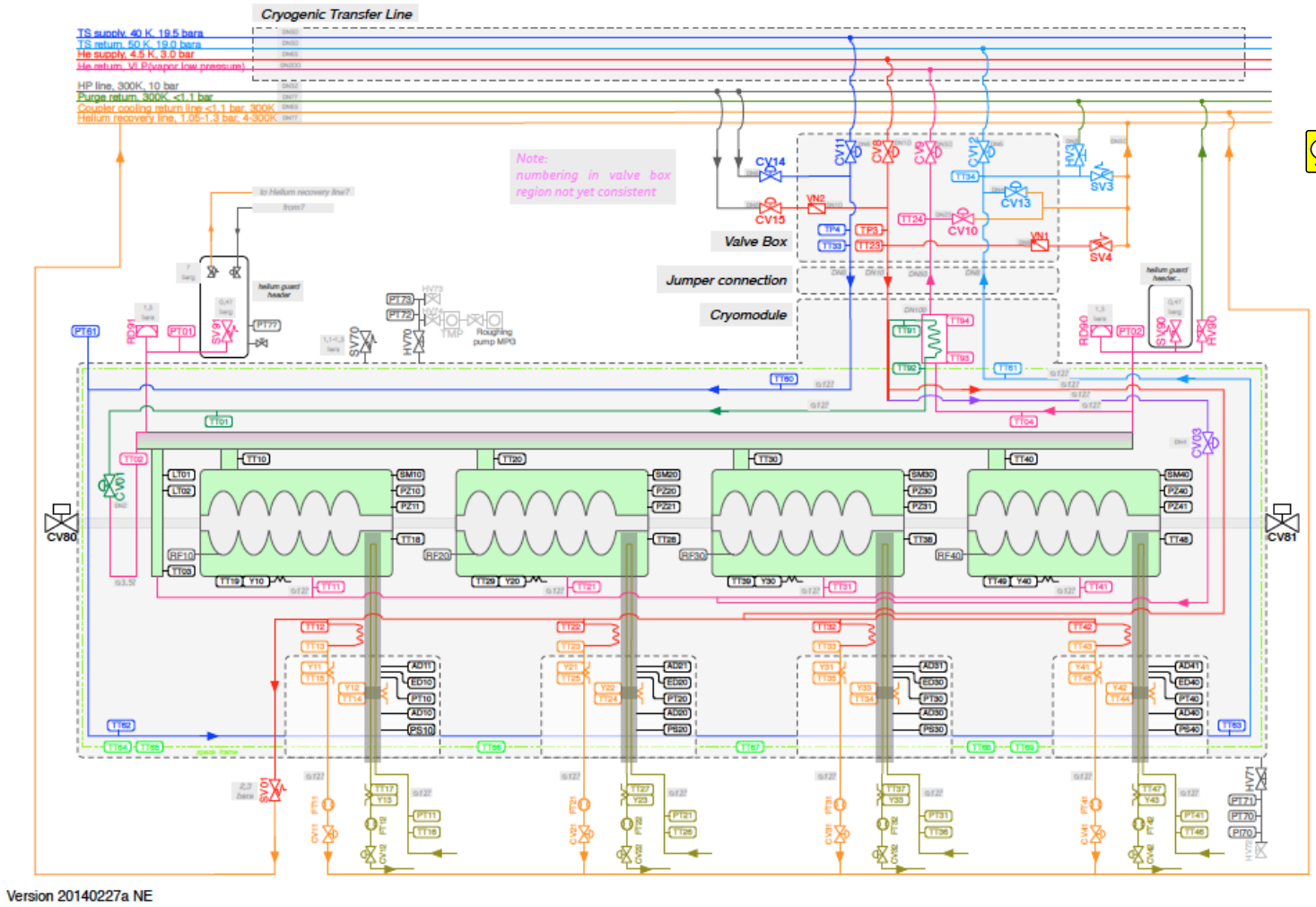
	Watts to 2 K							4.5 K Liquefaction (g/s)	Watts to ~50 K
	Static				Dynamic			Total	Total
	Others	Valves	Coupler	**Total**	Beam	Cavity	**Total**		
1 Spoke	3.3	0.2	3.5	**7**	1.5	5.0	**6.5**	0.092	30
1 MB	6.3	0.2	6.8	**13.3**	3.3	20	**23.3**	0.092	46.5
1 HB	6.3	0.2	6.8	**13.3**	3.3	24.4	**27.7**	0.092	46.5

Connection between Elliptical Cavity CM and Cryogenic Distribution Line



He II produced at each CM

ESS Accelerator Cryoplant (ACCP)

EUROPEAN SPALLATION SOURCE

- Provides cryogenic cooling to Cryomodules
  - 13 Spoke and 30 Elliptical (Stage 1)
  - Sized to allow an additional 14 Elliptical Cryomodules for design contingency (Stage 2)
- Allows for number of operating modes
- Connected to the cryomodules via a cryogenic distribution system
- High availability and turn down capability are important features
- Compressor heat is absorbed by Lund District Heating System (unique ESS feature)

ACCP Capacities

EUROPEAN SPALLATION SOURCE

Operation modes		2 K Load, W			4.5 K Load		40-50 K, W
		Isothermal	Non-isothermal	Total	4.5 K, W Total	Liquefaction, g/s	Total
Stage 1 2019-2023	Nominal	1860	627	2478		6.8	8140
	Turndown	845	627	1472		6.8	8140
	Standby				1472	6.8	8140
	TS Standby	-	-	-	-	-	8140
	Maximal Liquefaction	Loads in standby mode plus maximum liquefaction rate at rising level into the storage tank					
Stage 2 2023-…	Nominal	2226	824	3050		9.0	10819
	Turndown	1166	824	1990		9.0	10819
	Standby				1990	9.0	10819
	TS Standby	-	-	-	-		10819
	Maximal Liquefaction	Loads in standby mode plus maximum liquefaction rate at rising level into the storage tank					

ACCP Status

EUROPEAN SPALLATION SOURCE

- Heat loads and capacities determined
- Industry studies completed
- Design choices have been made
  - No LN_2 precooling
  - Optimized cold compressor and turboexpander hardware for Stage 1 & Stage 2 to minimize energy consumption
- Detailed Specification and SOW complete and ITT released
- Expected placement of order in February 2015
  - Installation, LHe and GHe storage and Helium Recovery will be separate procurements
- Plant is expected to fully commissioned by June 2018

Cryogenic Distribution System

EUROPEAN SPALLATION SOURCE

- 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
- Separate isolation vacuums in the distribution lines and cryomodules
- Operating modes defined
- Conceptual design complete
- Detailed design and production via IKC or commercial contract will start by Q3 2014
- Cryogenic Distribution System must be complete and installed by December of 2017

Linac CDS – function and layouts

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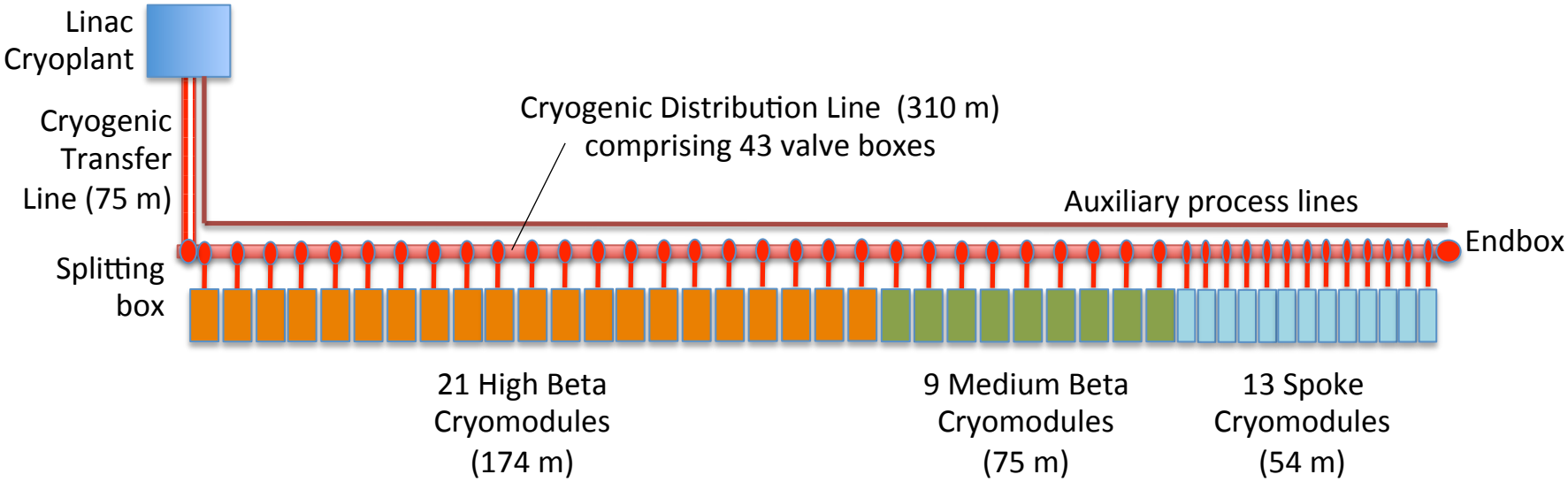
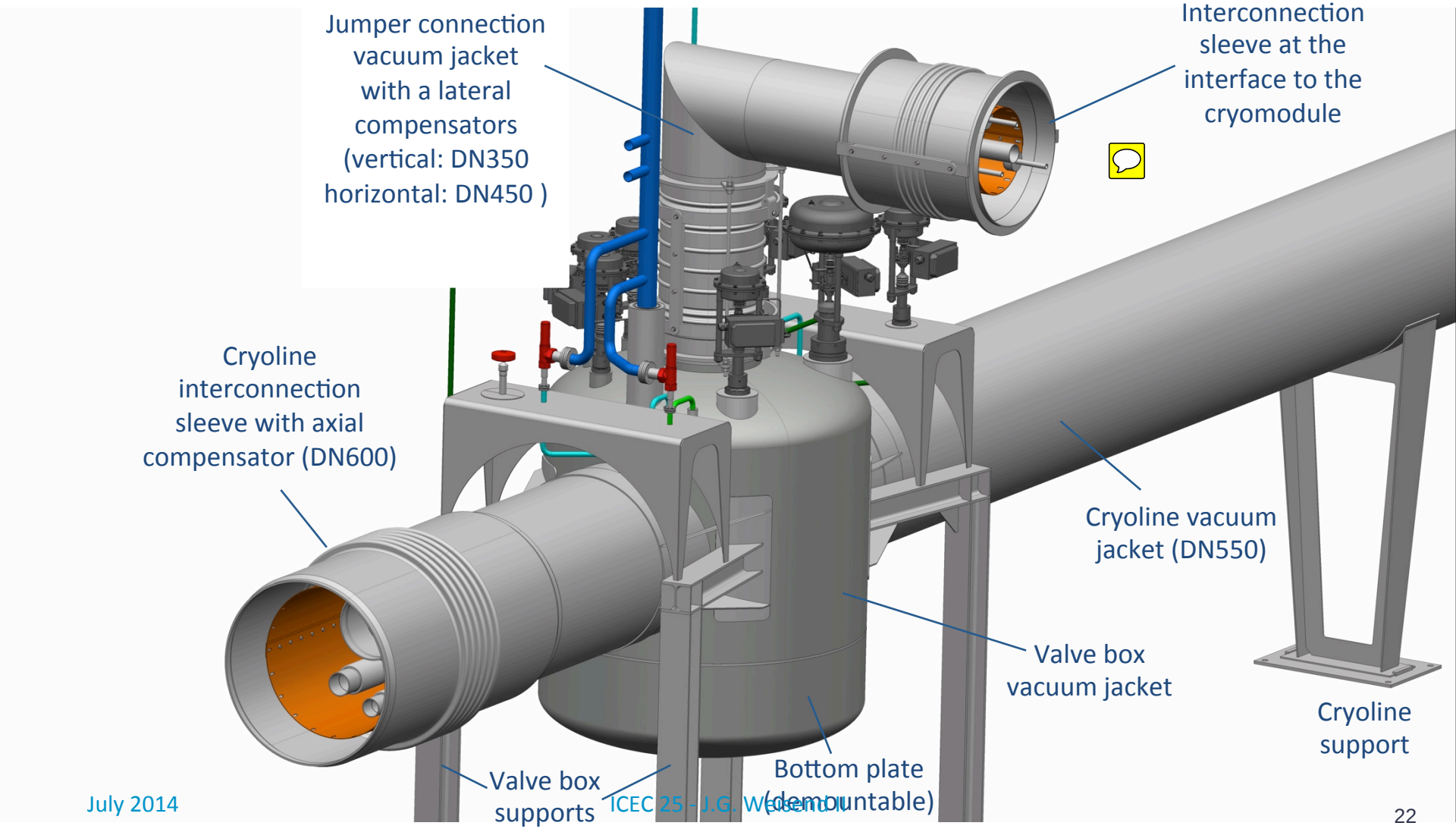
Cryogenic System of the Optimus Linac

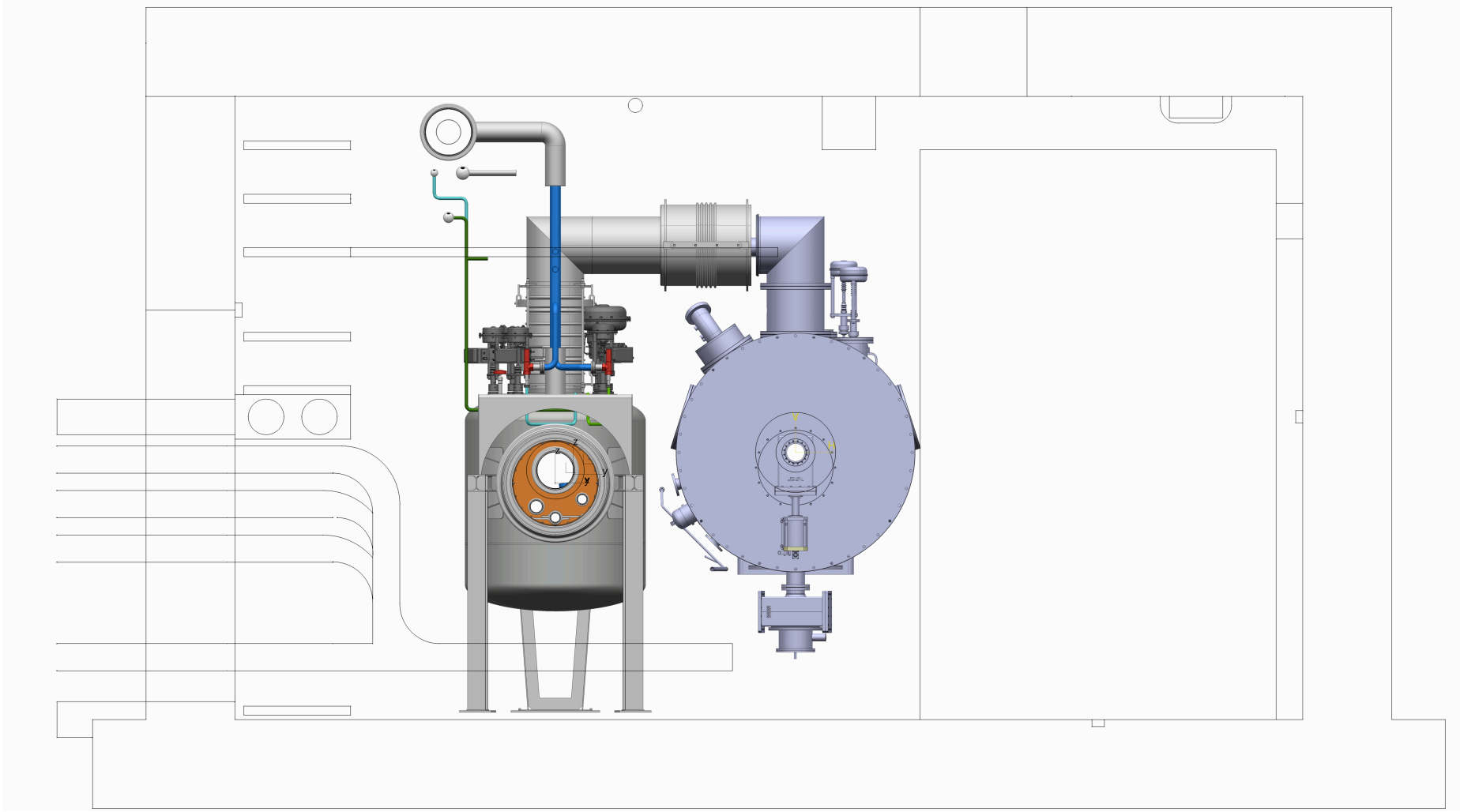


Valve box – vacuum jacket



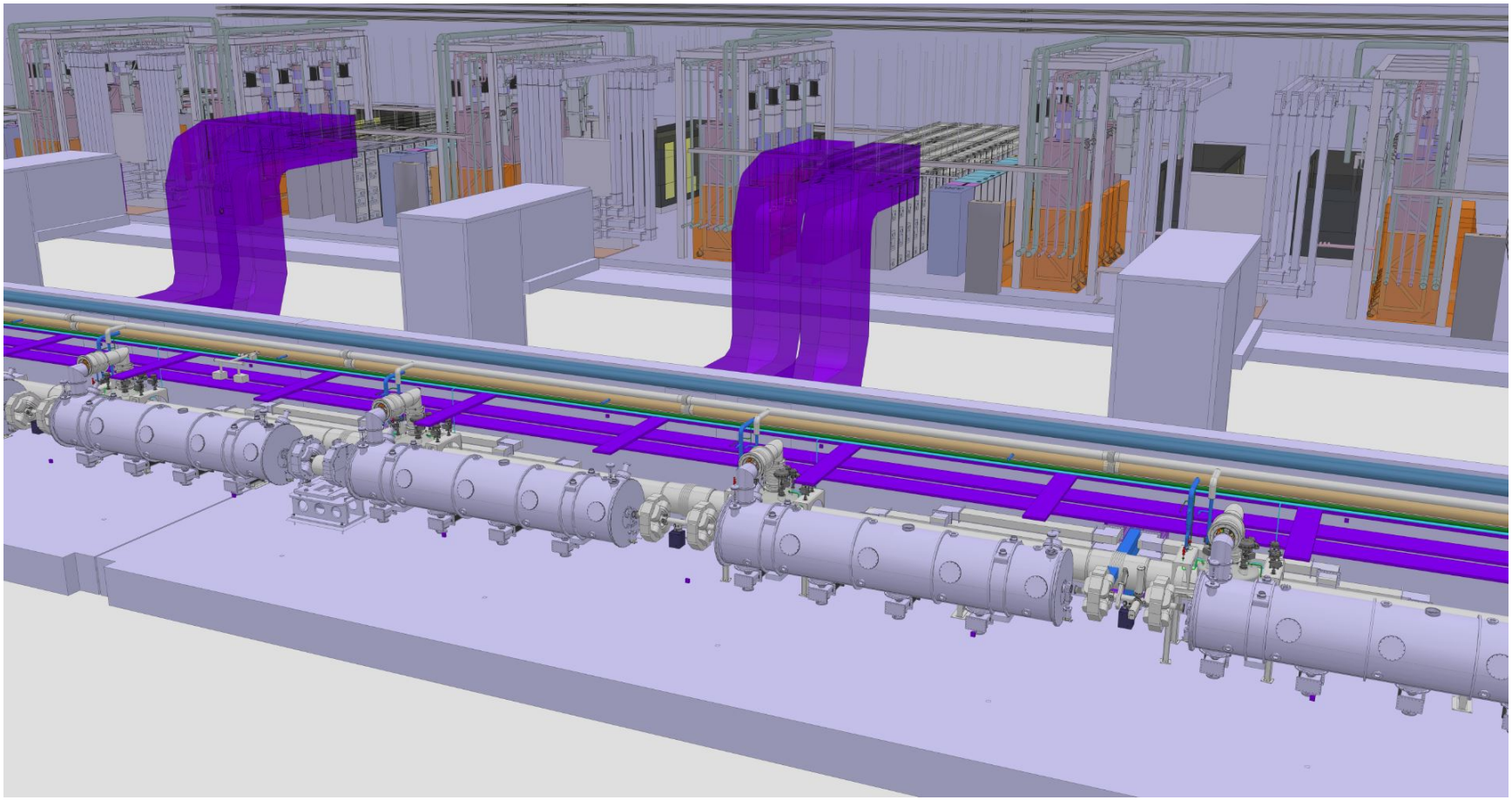
Cryogenic Distribution Line

EUROPEAN SPALLATION SOURCE



Elliptical Cryomodules in ESS Tunnel

EUROPEAN SPALLATION SOURCE



Target Moderator Cryoplant

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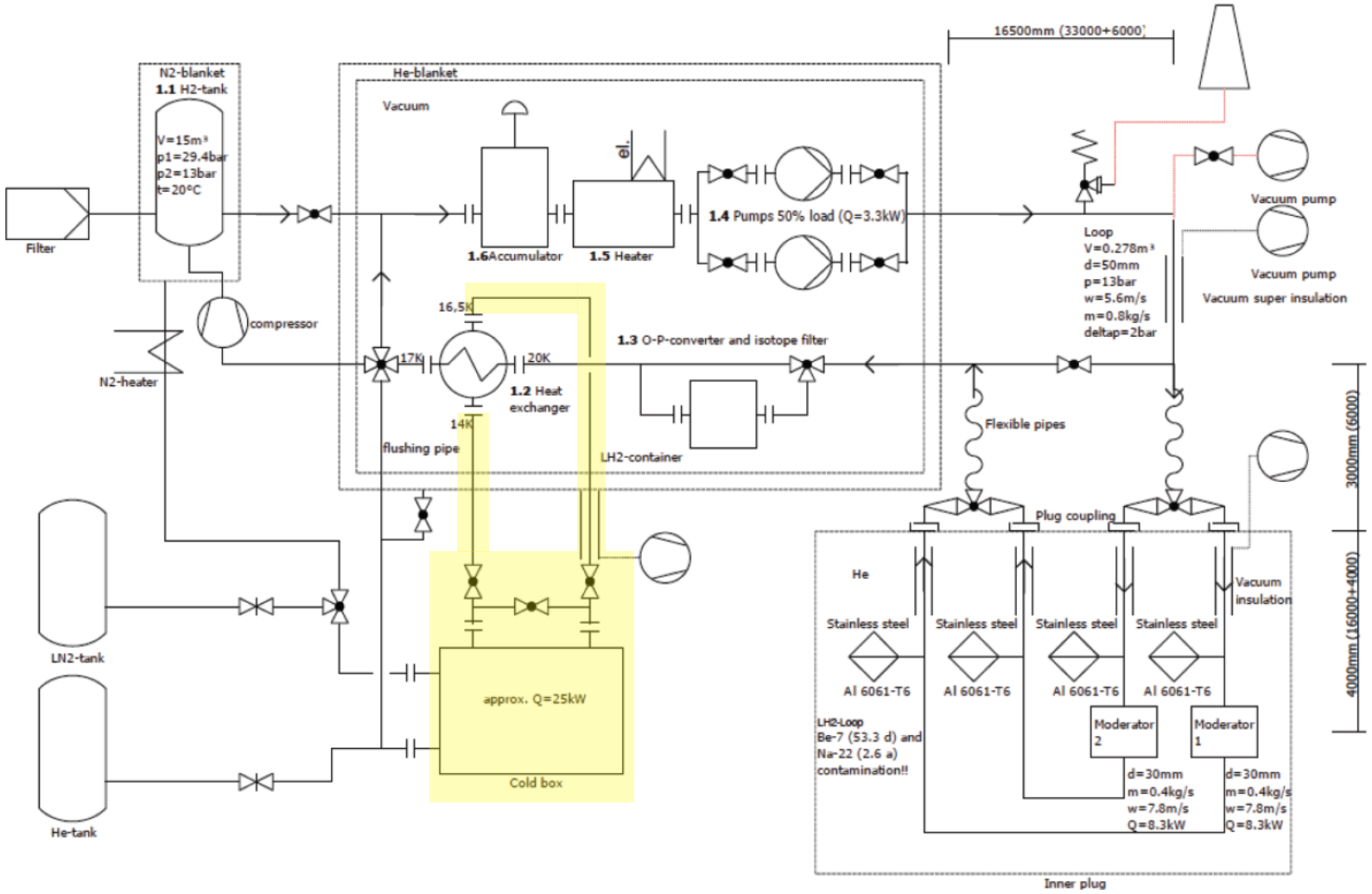
- Cools the Supercritical H_2 neutron moderators that surround the target
- Provides 20 kW of cooling at 16.5 K via GHe to the He/ supercritical H_2 heat exchanger
  - Moderator design is still under development and final heat load won't be known until summer 2014
  - ESS Target Division responsible for the supercritical H_2 system
- Compressor heat is absorbed by Lund District Heating System (unique ESS feature)
- Cryoplant should be ordered in August of 2015 and fully commissioned by June of 2018

Draft Schematic of LH_2 Moderator Loop showing connection to the Target Cryoplant

EUROPEAN SPALLATION SOURCE



Test and Instruments Cryoplant

EUROPEAN SPALLATION SOURCE

- Provides cooling at 2 K, 40 K and 4.5 K liquefaction for elliptical cryomodule testing
  - 2 K operation done via warm vacuum pumps
- During ESS operations, provides up to 7500 l per month of LHe to the instruments
  - Helium is recovered, purified and reliquefied
- Sufficient LHe storage planned to allow several weeks of Science Ops in the case of cryoplant failure

Test and Instruments Cryoplant Capacity and Status

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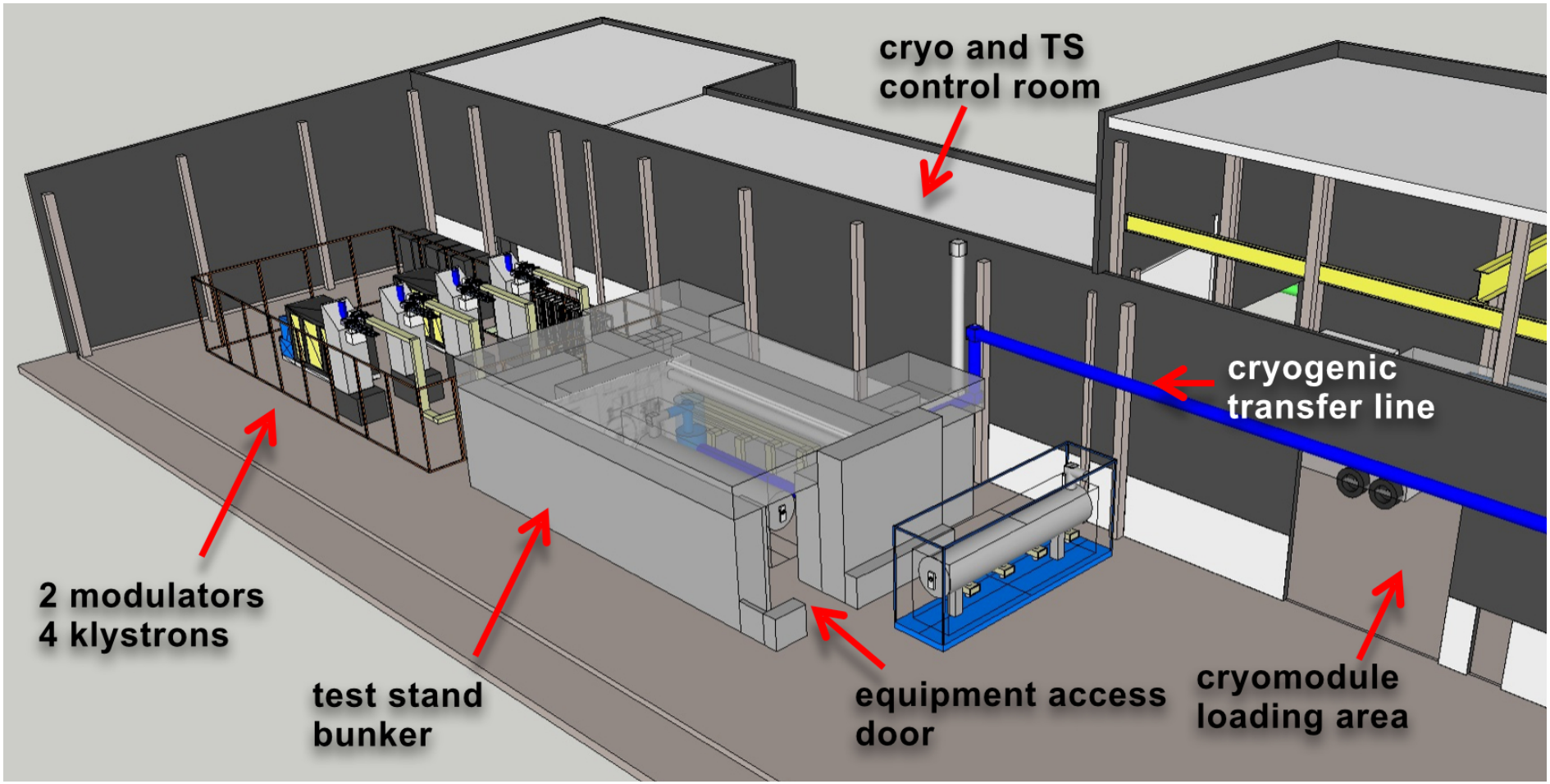
- The plant will produce:
  - 75 W @ 2 K,
  - 422 W @ 40 K
  - 0.4 g/s at 4.5 K for coupler cooling
- A plant this size exceeds the 7500 l / month liquefaction requirement
- Cryoplant should be ordered in August 2015 and fully commissioned by July 2017

Cryomodule Test Stand Showing Connection to T&I Cryoplant

EUROPEAN SPALLATION SOURCE



Helium Recovery and Storage

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- The ESS goal is to recovery, purify and reuse as much He as possible
- ACCP and TICP cryoplants will share a common gas system while TMCP has separate storage that can be cross connected
- The system will include a separate cryogenic purifier
- Systems will be provided by IKC or separate contracts
- Expected He Storage Capacities:
  - LHe
    - 20 m^3 (Includes storage for second fill of linac)
    - 5 m^3 (Backup for Instruments He)
  - GHe (20 Bar)
    - 900 m^3 - sufficient to hold all the linac inventory
  - GHe (200 Bar)
    - 12 m^3 - Instrument He storage

Conceptual ESS Cold Box Room Layout

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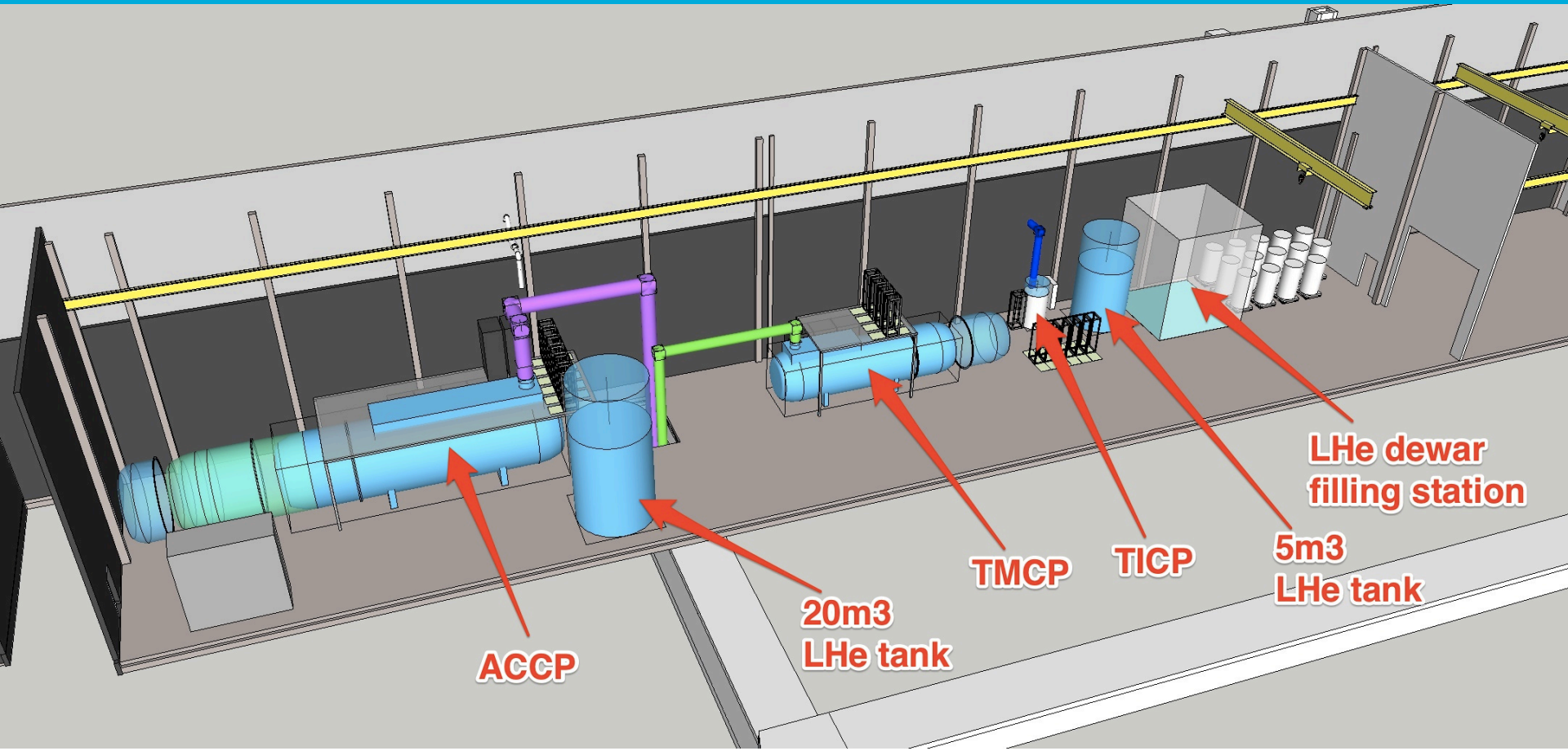

The ESS Commitment: A Sustainable Research Centre

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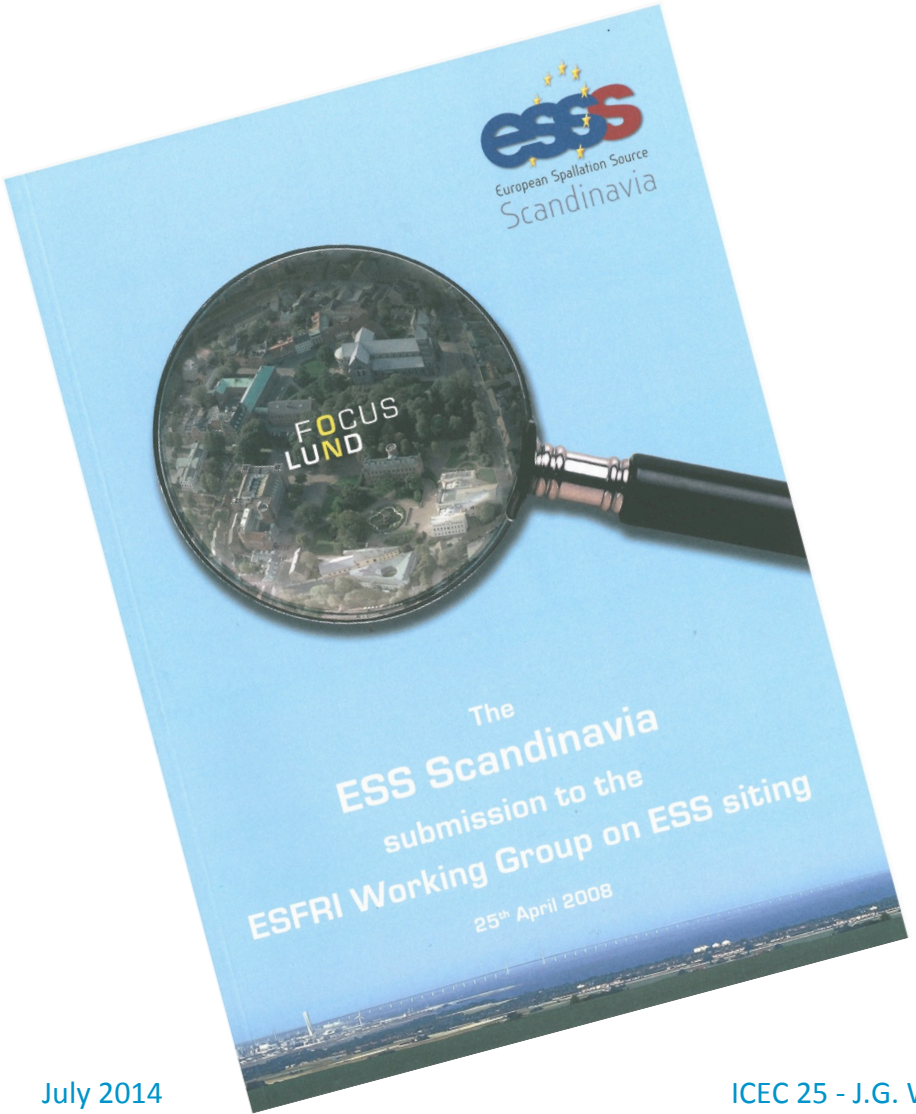


- ✓ **Responsible**

  Energy Efficiency

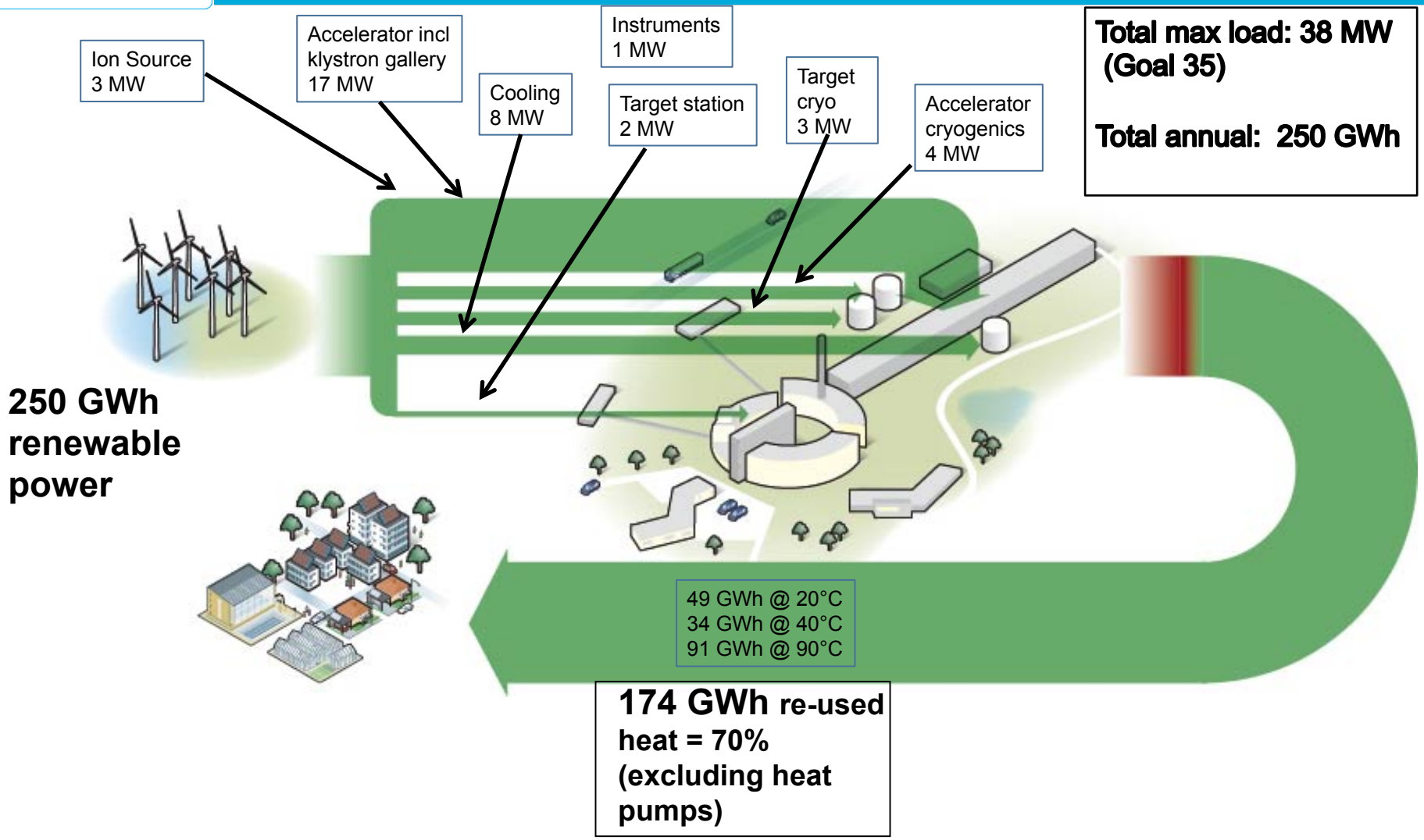
- ✓ **Recyclable**

  ESS's cooling is Lund's heating

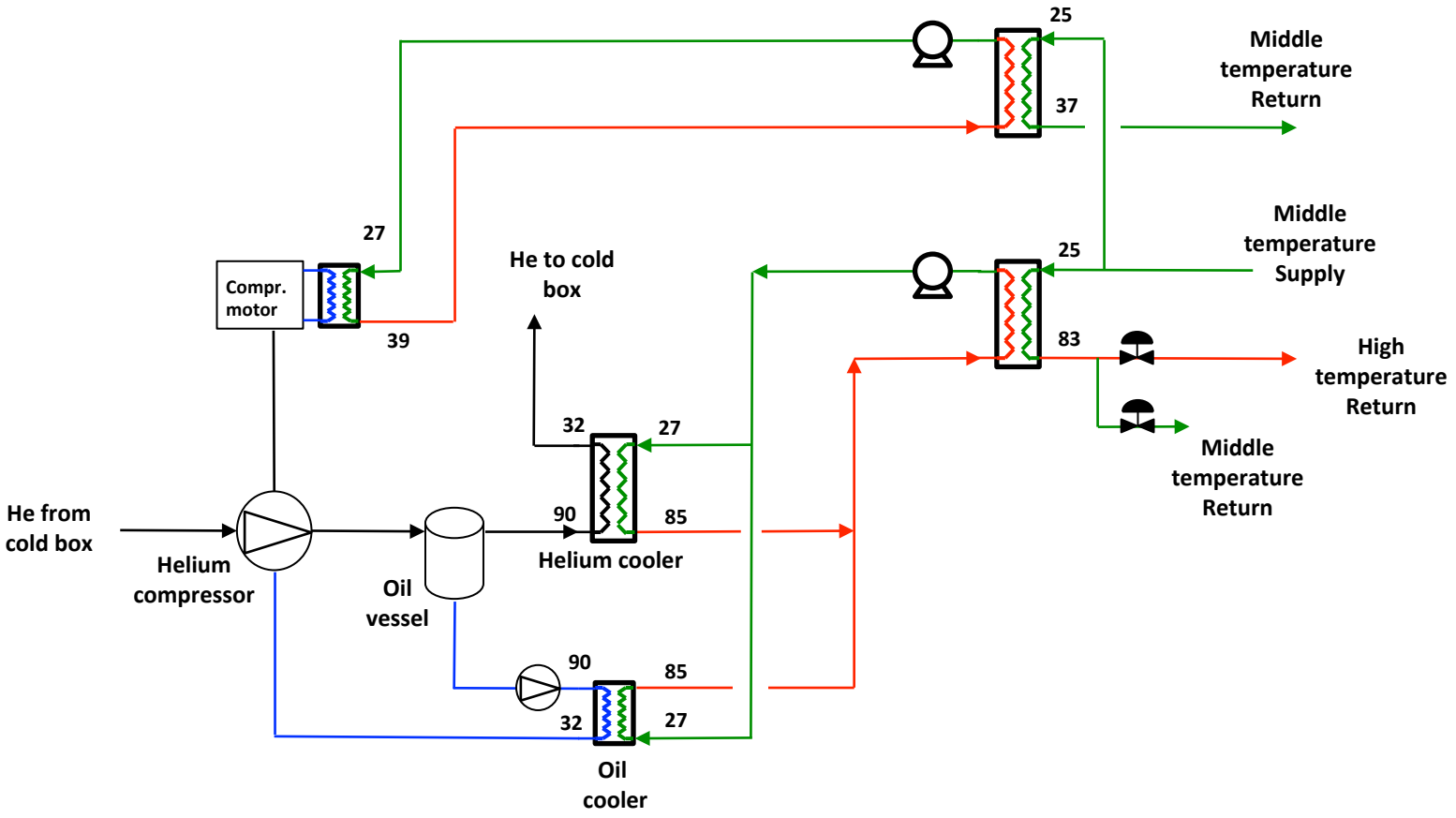
- ✓ **Renewable**

  Power from renewable sources

Energy Inventory ESS 2012



Energy Recovery from ACCP Compressors



Opportunities for In Kind Contributions to the ESS Cryogenic System

EUROPEAN SPALLATION SOURCE

- There are many opportunities for IKC in the ESS Cryogenics System and we are very happy to discuss any of them.
- Possibilities include:
  - Cryoplants (particularly the TMCP and TICP)
  - Cryogenic Distribution System
  - He Recovery and storage
  - Assistance with installation and commissioning

ESS Cryogenic System

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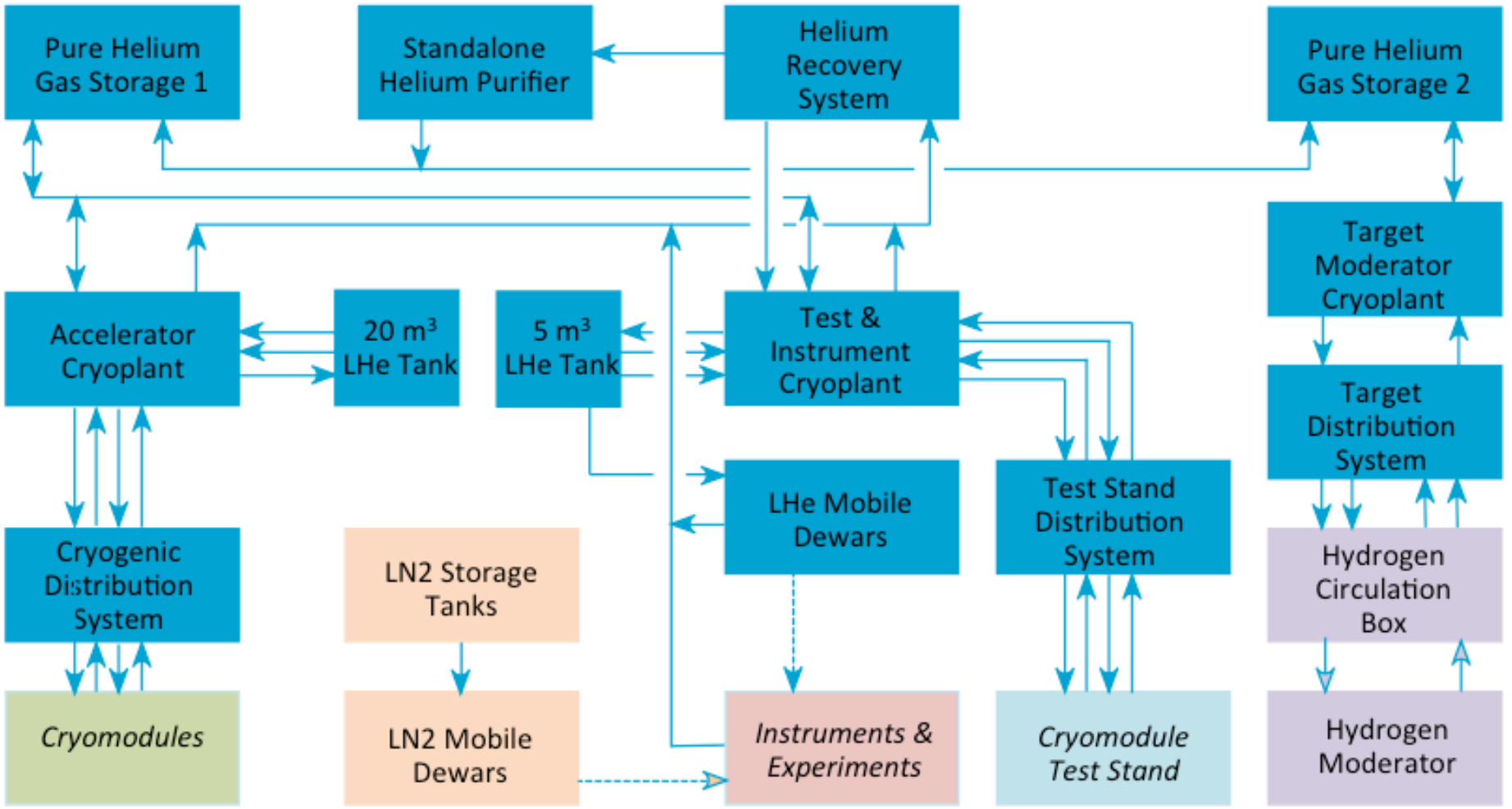
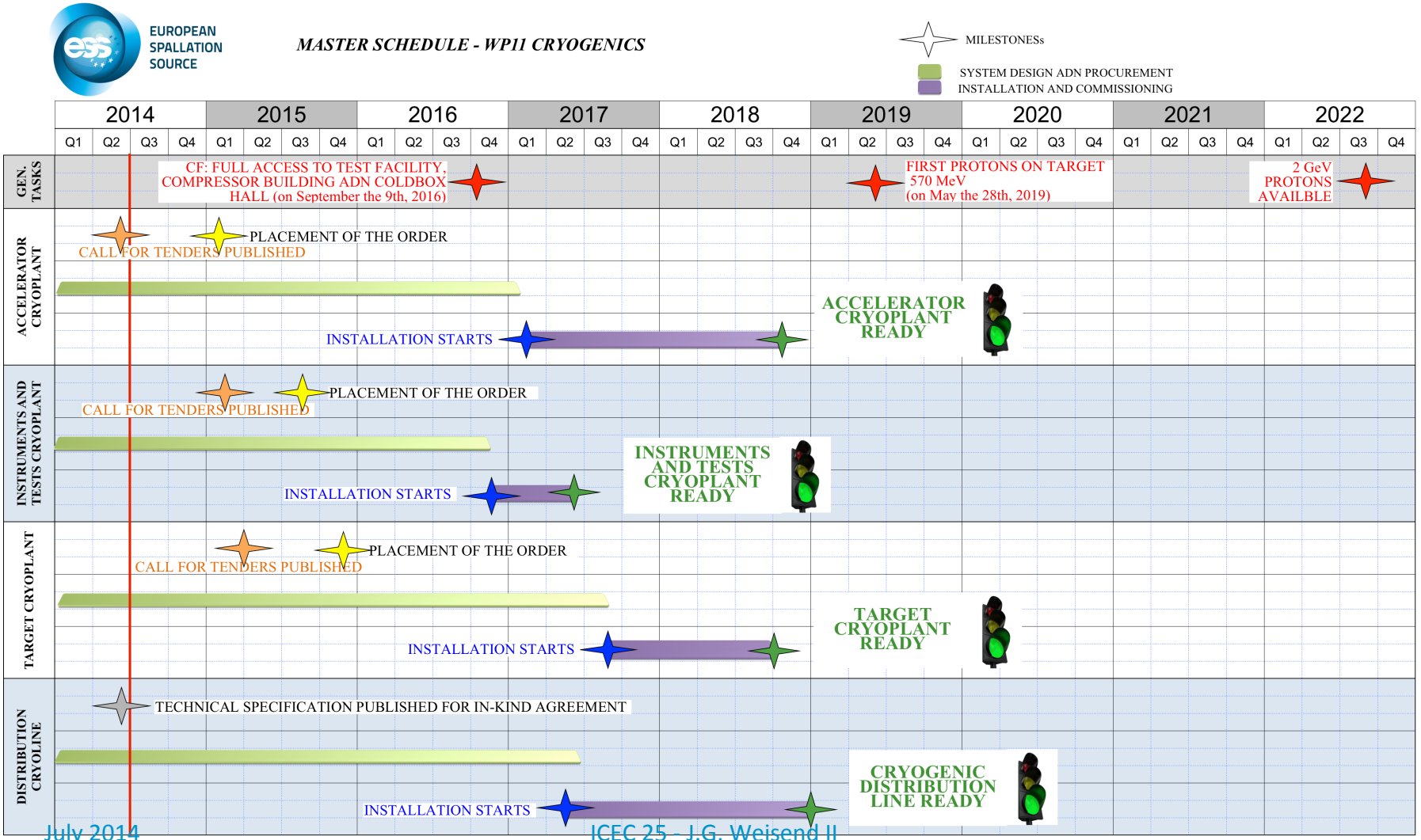


High Level Schedule

EUROPEAN SPALLATION SOURCE



DATA EXTRACTED BY P6 PLANNING - JUNE 2014

PREPARED BY P. ARNOLD & L. LARI
CHECKED BY J. WEISEND
APPROVED BY M. LINDROOS

Summary

EUROPEAN SPALLATION SOURCE

- Cryogenics will play a major role in ESS and affects the accelerator, target and instruments projects
- Work is well underway
  - A very skilled team has been assembled
  - Industry studies for the largest of the plants have been completed
  - Conceptual designs and technical specifications are complete or under preparation
  - Required buildings and utilities have been defined and are under detailed design
  - Sizable procurements will start in 2014 and 2015
- Significant Opportunities for IKC exist
- ESS has just received the green light to start construction