EUROPEAN
SPALLATION
SOURCE

Progress of the European Spallation Source Project

The integration of many systems

PRESENTED BY FAY CHICKEN – WORK PACKAGE MANAGER HARDWARE CORE

2023-05-24

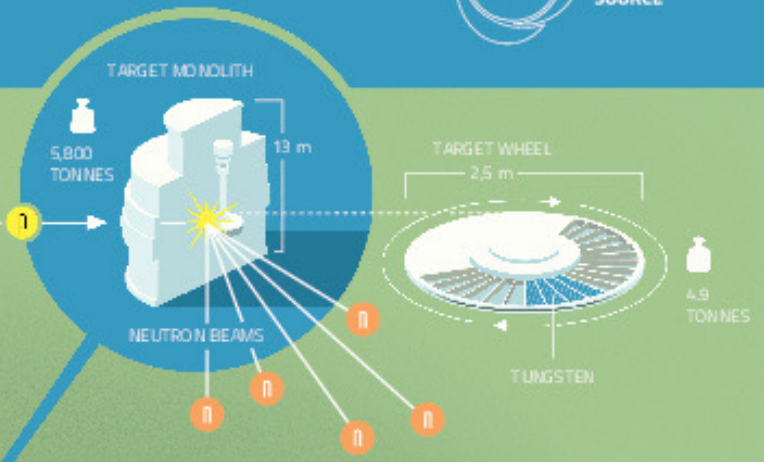

What is the European Spallation Source?

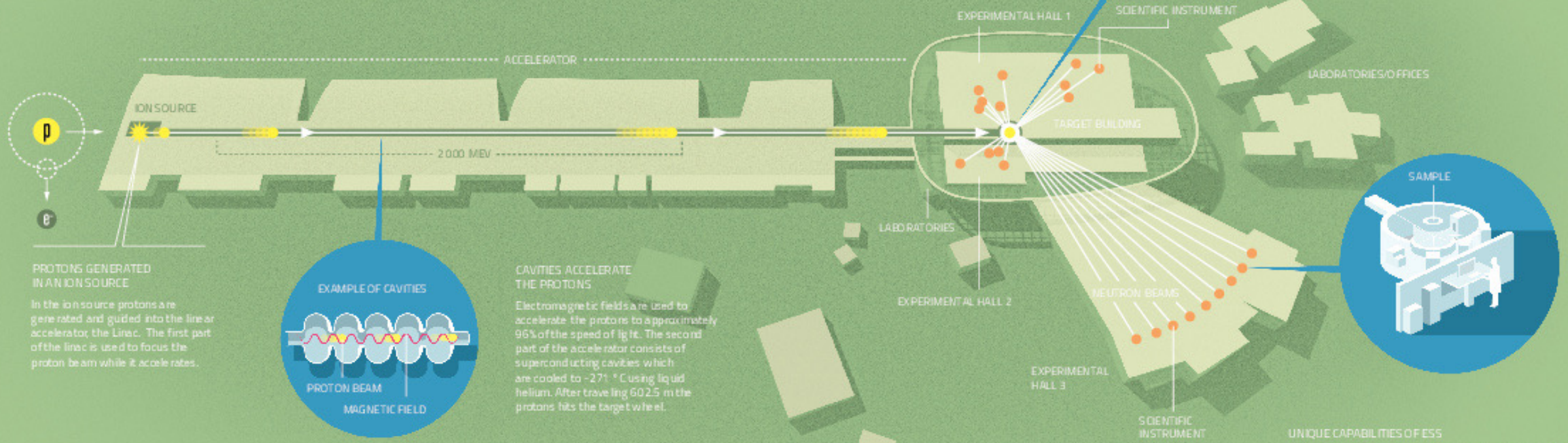
European Spallation Source

The European Spallation Source (ESS) is a multi-disciplinary research centre based on the world's most powerful neutron source. ESS will give scientists new possibilities in a broad range of research, from life science to engineering materials, from heritage conservation to magnetism. ESS is a pan-European project, with Sweden and Denmark serving as host countries. The main research facility is being built in Lund, Sweden, and the Data Management and Software Centre (DMSC) is located in Copenhagen, Denmark.

THE TARGET IS THE NEUTRON SOURCE

When the accelerated protons hit the rotating tungsten target wheel spallation occurs and neutrons are scattered from the tungsten nucleus. The more neutrons produced and collected in the target, the "brighter" the neutron source. The neutrons are directed through moderators and neutron guides to the scientific instruments where they are used for experiments. The Target monolith consists of the Target wheel, moderators, cooling systems and shielding and weighs approximately 5,800 tonnes.





PROTONS GENERATED IN AN ION SOURCE

In the ion source protons are generated and guided into the linear accelerator, the Linac. The first part of the linac is used to focus the proton beam while it accelerates.

CAVITIES ACCELERATE THE PROTONS

Electromagnetic fields are used to accelerate the protons to approximately 96% of the speed of light. The second part of the accelerator consists of superconducting cavities which are cooled to -271 °C using liquid helium. After traveling 602,5 m the protons hits the target wheel.

TOTAL BUILDING AREA 65 000 m²

The ESS facility will be approximately 650 metres in total length. The target building will be 125 metres long, and about 30 metres high. The 537-meter-long accelerator tunnel is built underground and will be covered with soil.

Concrete:	50 000 m³
Re bar:	6 000 tonnes
Pipes:	40 km
Cables:	2,000 km
Total volume:	400,000 m³

2023-05-24

PILES TO AVOID MOVEMENTS

The heavy Target building and experimental halls are resting on a total of 6,400 piles of different types, in order to avoid unwanted movements in the structure.

UNIQUE CAPABILITIES OF ESS

ESS will have 22 tailor-made instruments located in three experimental halls. Neutrons are excellent for probing materials on an atomic and molecular level – everything from motors and medicine, to plastics and proteins. The neutrons hit the sample and detectors register the neutron scattering, giving precise information about the material's structure and dynamics.

The European Spallation Source

ESS is a neutron spallation source for neutron scattering measurements.

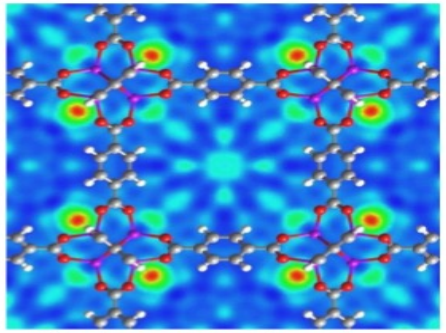
Neutron scattering can reveal the molecular and magnetic structure and behavior of materials:

- Structural biology and biotechnology, magnetism and superconductivity, chemical and engineering materials, nanotechnology, complex fluids, etc.

Neutrons are complementary to X-Rays (synchrotrons, X-FEL)

High beam power will open up new possibilities for neutron scattering experiments

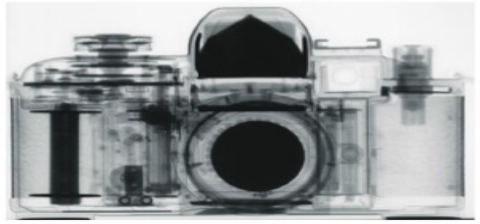
- Traditionally, low flux and “slow” experiments



Neutron scattering of hydrogen in a metal organic framework

Neutron radiograph of a flower corsage

X-Ray Image

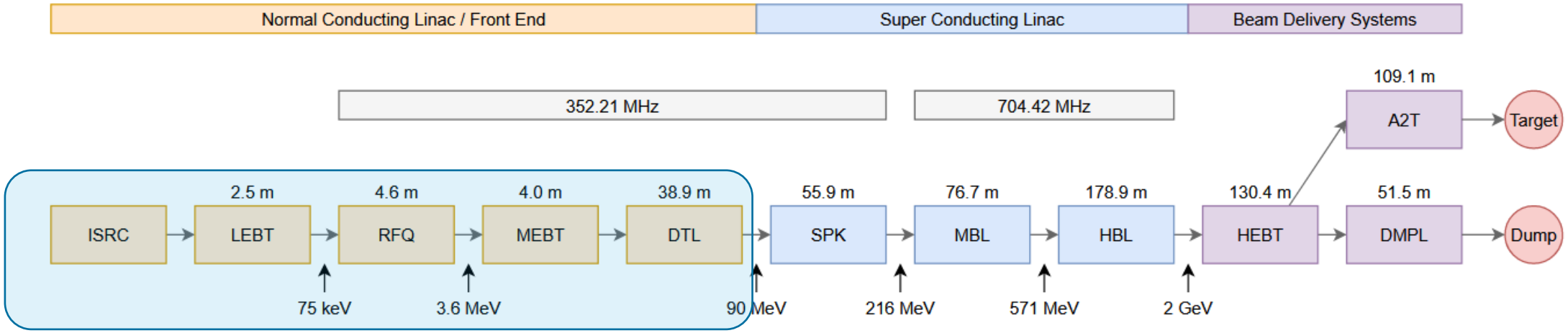


Neutron radiograph

Accelerator : Breakdown

❑ LINAC = Linear Accelerator

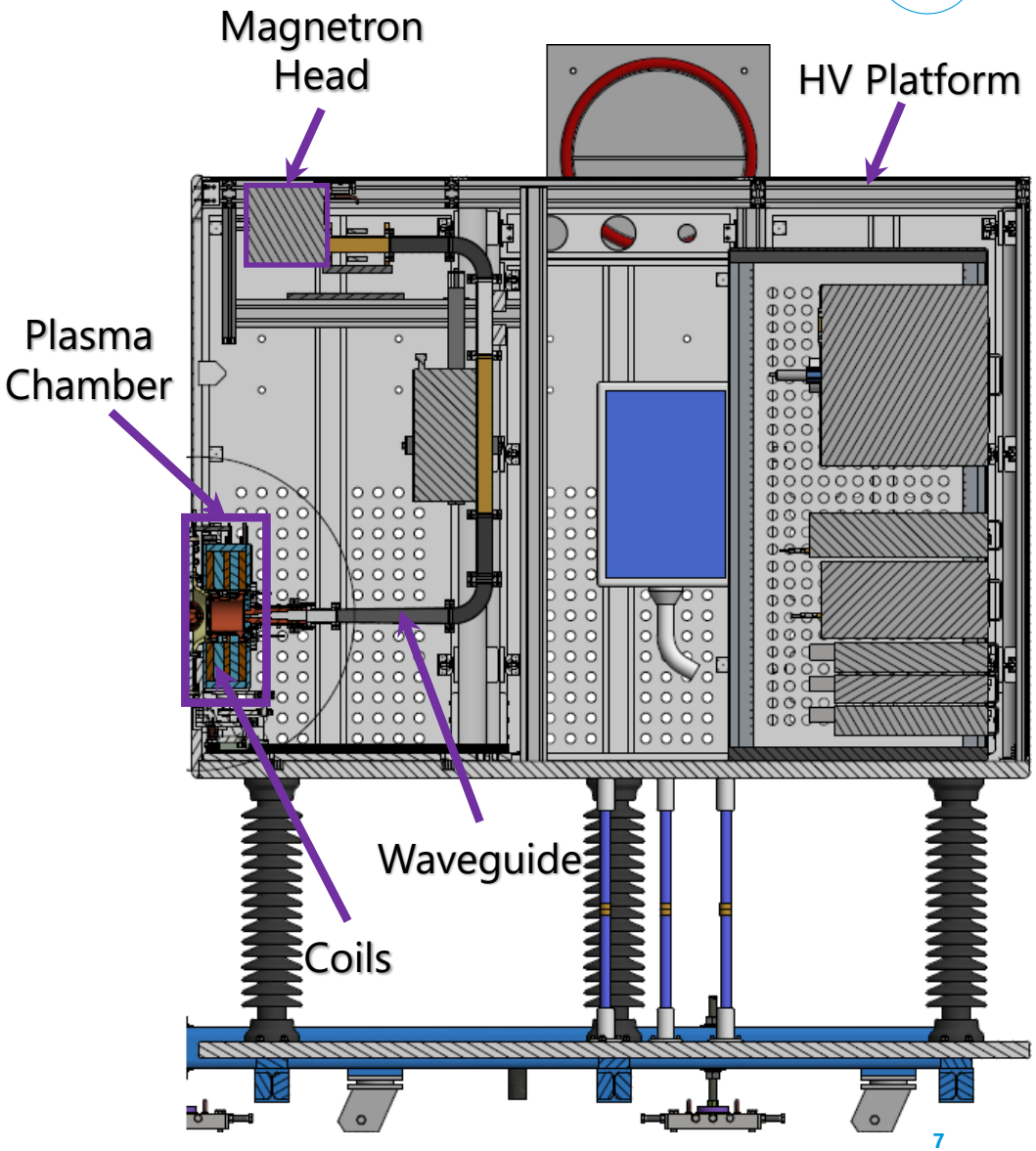
- ❑ Set of Systems dedicate to create and accelerate protons
- ❑ Maximum Speed : Close to Speed of light
- ❑ Two types of Systems : Beam Accelerator / Beam Transport
- ❑ To accelerate the proton beam at different energy levels we have different cavity types. And each cavity type has its frequency range of operation



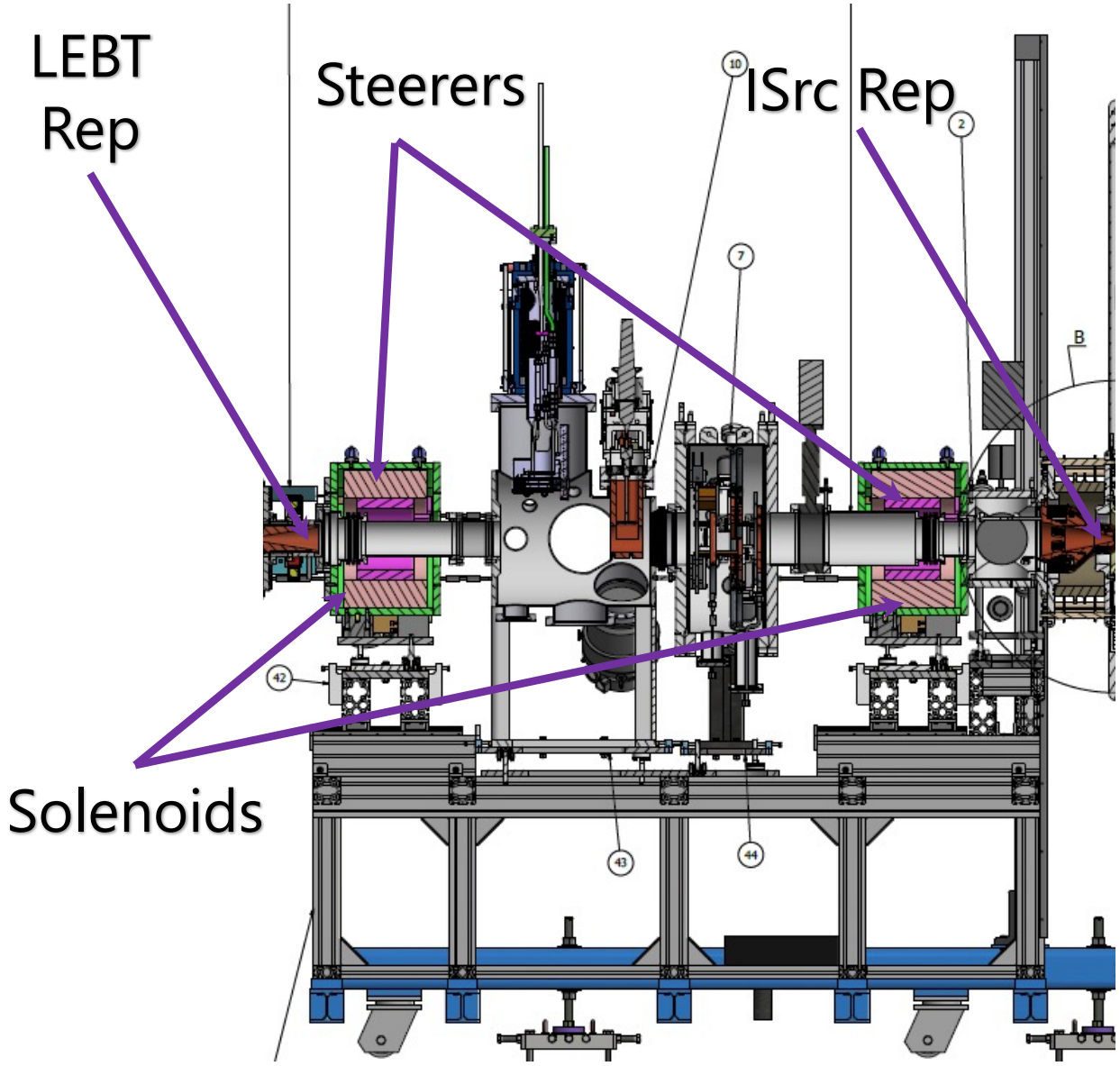
ISrc : The Ion Source

The NCL starts with :

- The Ion Source (ISrc)
  - Produces protons and launches them towards the LEBT.

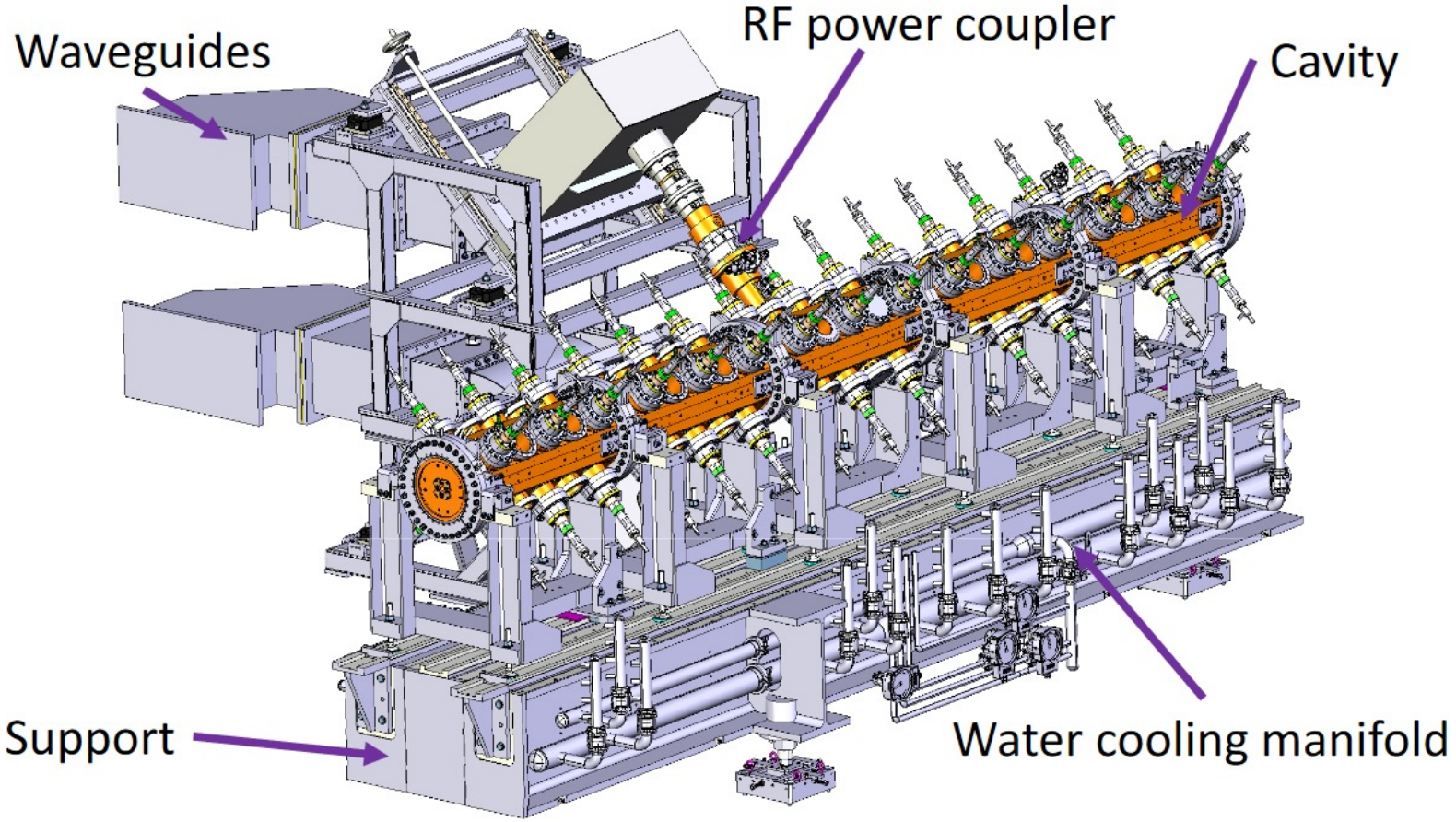


LEBT : Low Beam Energy Transport



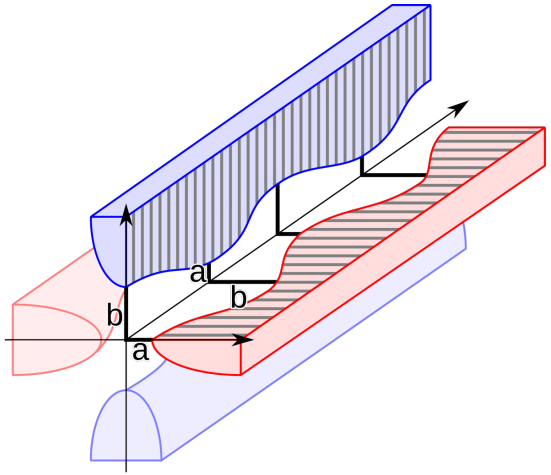
The LEBT is a transport channel with the main objective to focus and drive the beam of protons.

RFQ : Radiofrequency Quadrupole

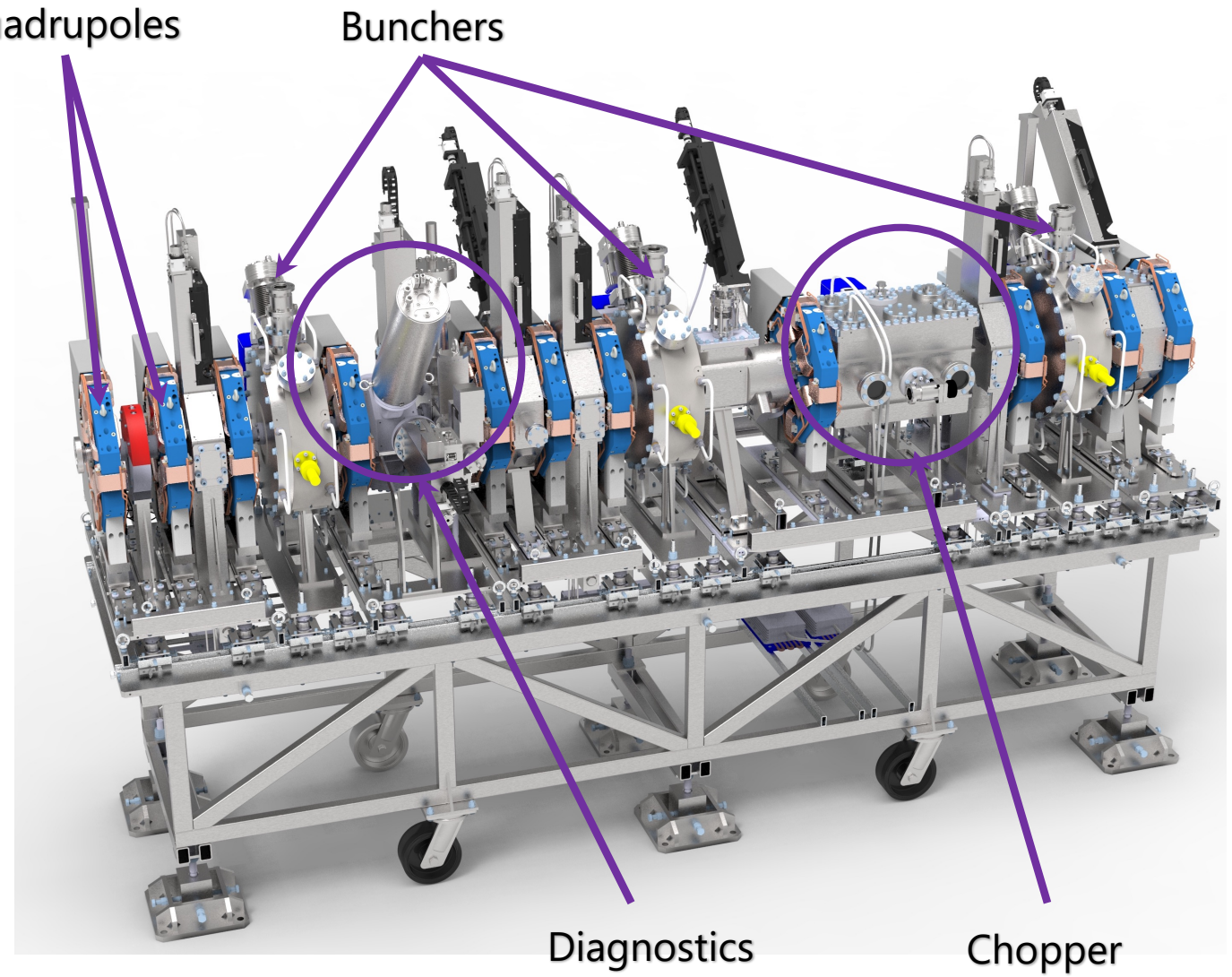


RFQ is a 4.6m long, four-vane radiofrequency quadrupole.

RFQ combines acceleration and focusing , bunching.



MEBT : Medium Energy Beam Transport

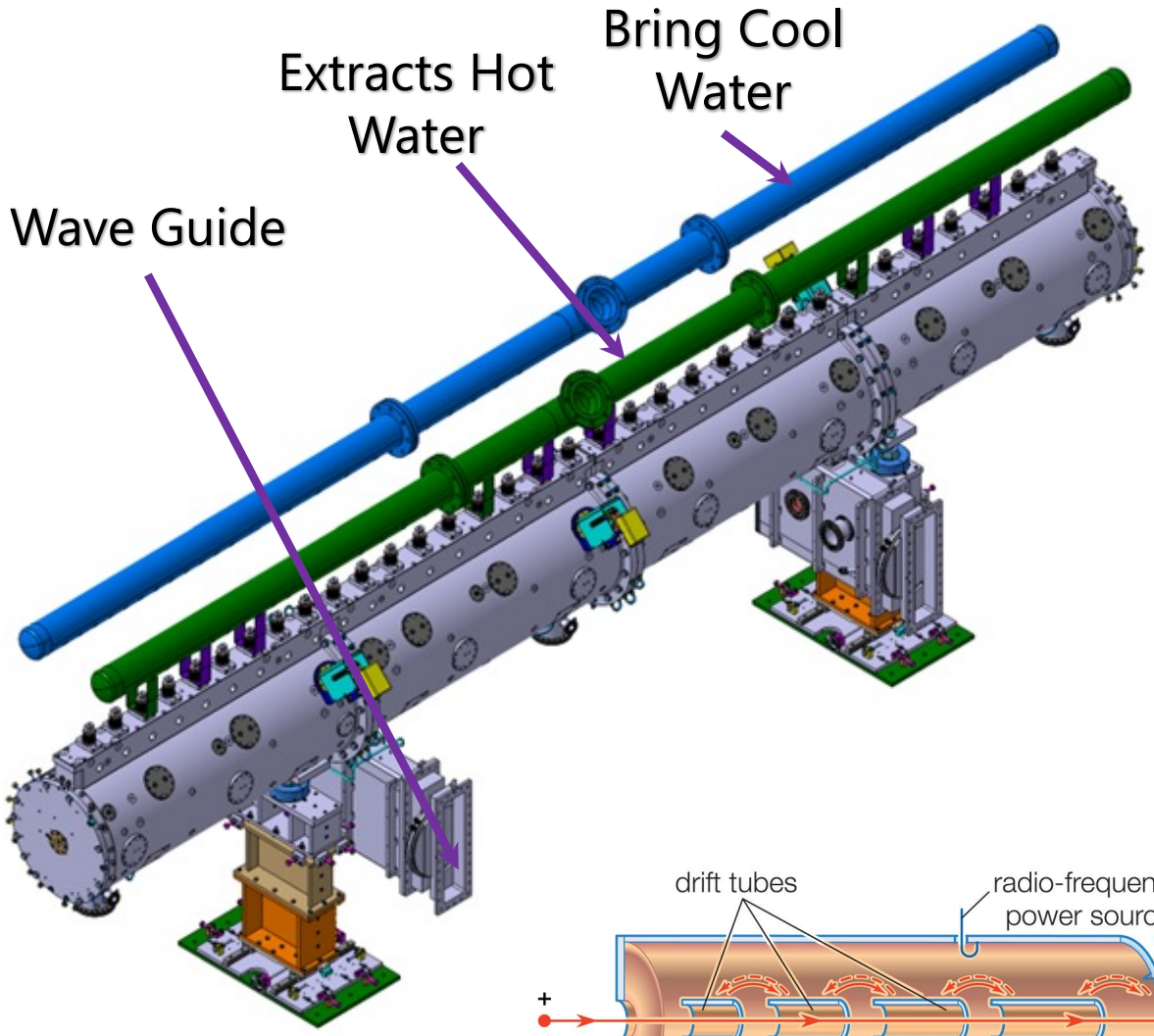


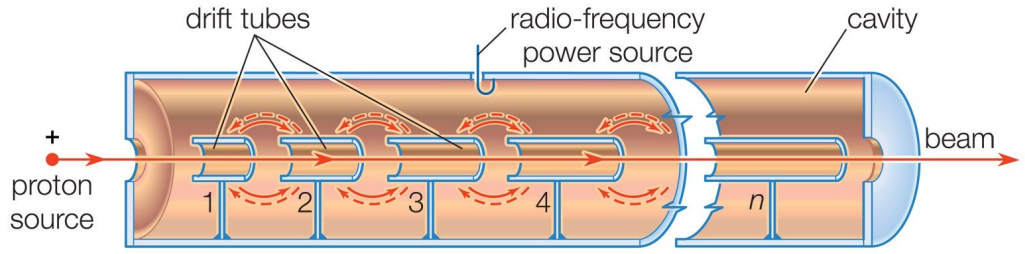
MEBT is another transport line to bring the beam of protons to the DTL.

Quadrupoles focus the beam using the magnetic field (don't accelerate).

Bunchers use magnetic field to keep the beam split in bunches.

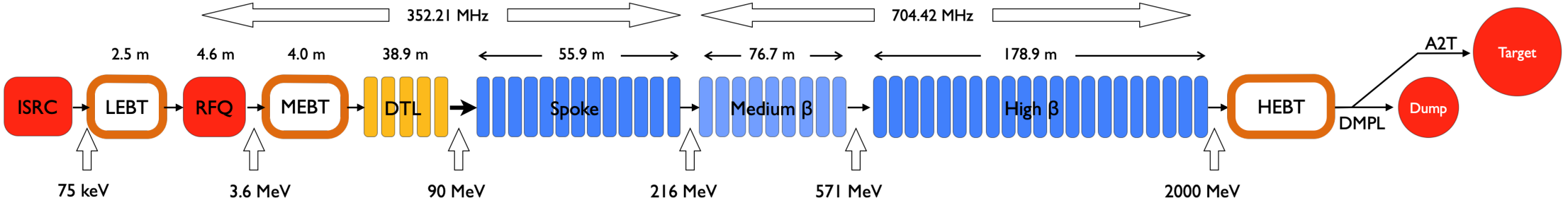
DTL : Drift Tub Linac





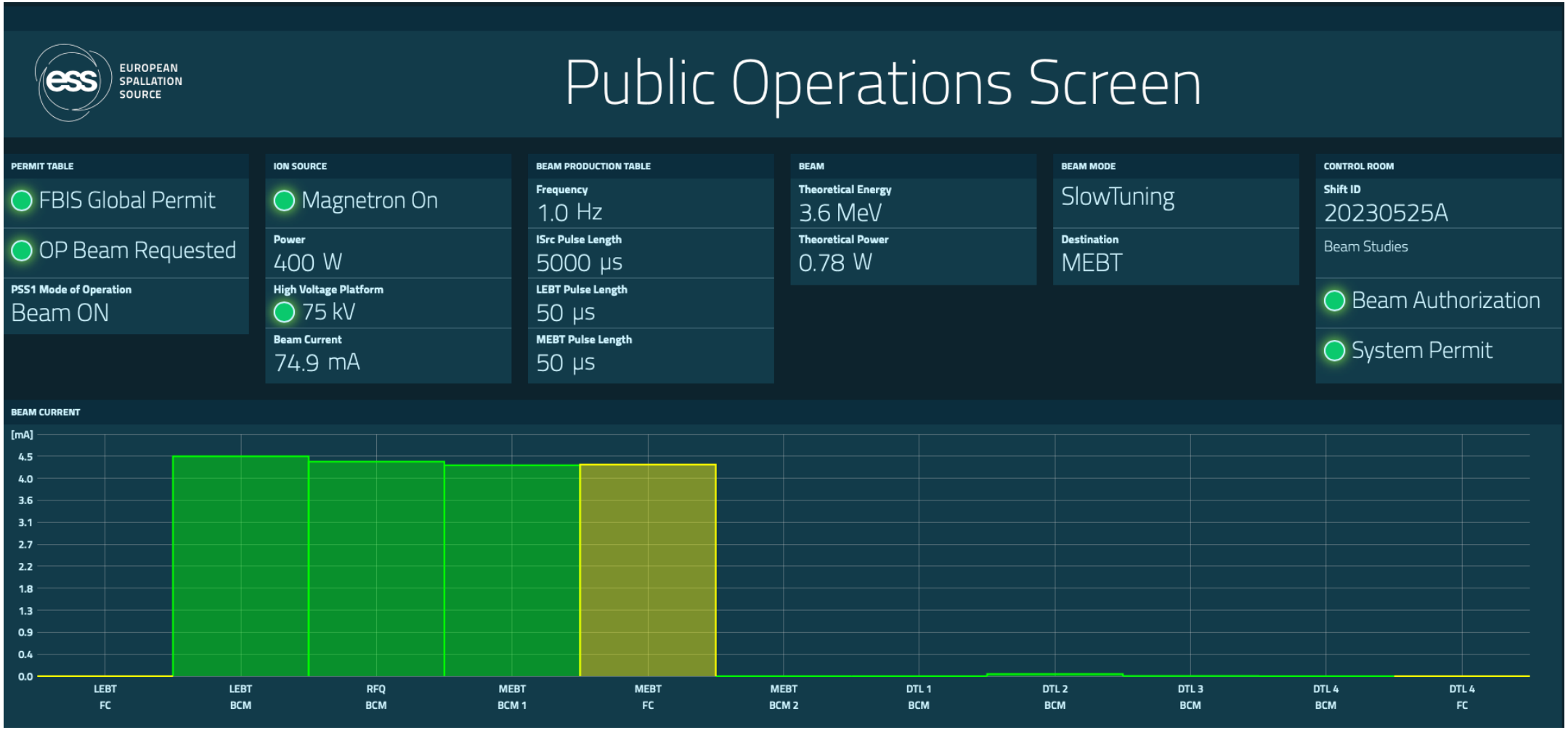
DTL : Five DTL tanks will accelerate the beam to ~90 MeV using Radio Frequency Power source.

Current Status: Phase 3 of Beam Commissioning

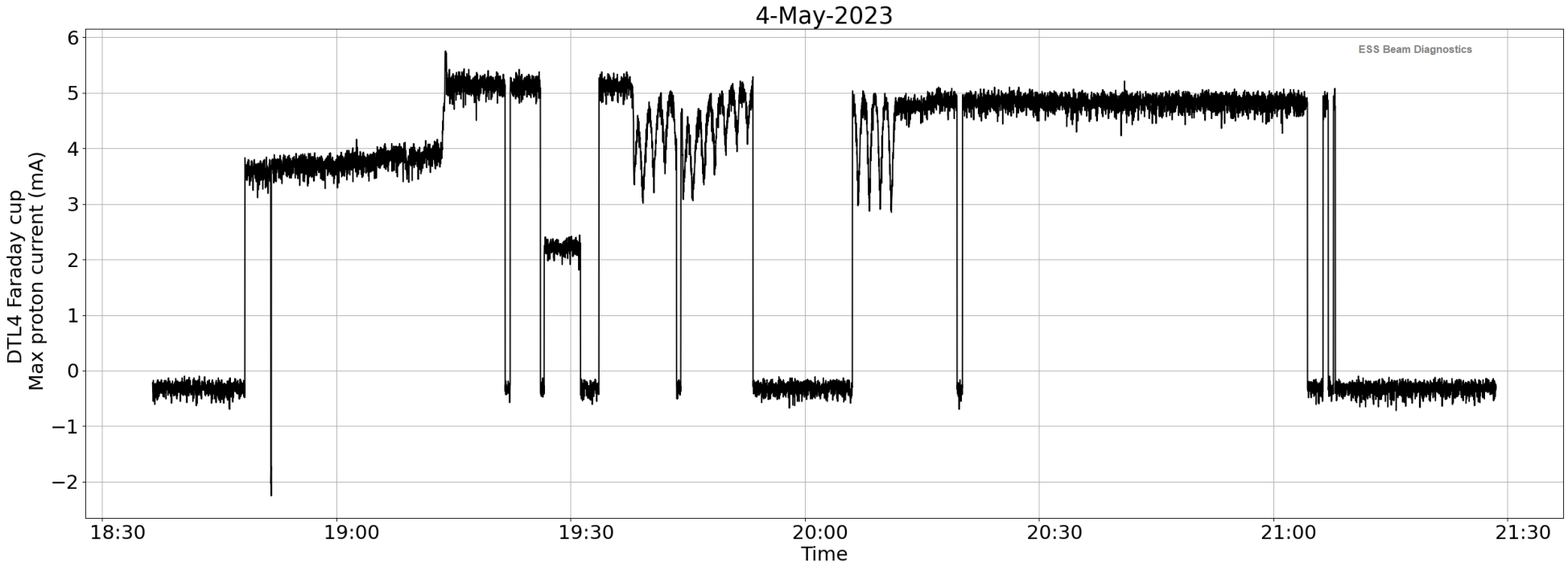


Work has begun on Phase 3 of beam commissioning, up to DTL4.
Currently running 42M of accelerator from Ion Source to DTL4.
DTL5 is being prepared and will be installed in July once commissioning of DTL4 is complete.
Spoke cryomodules are being prepared and first module will soon be ready for cooldown.

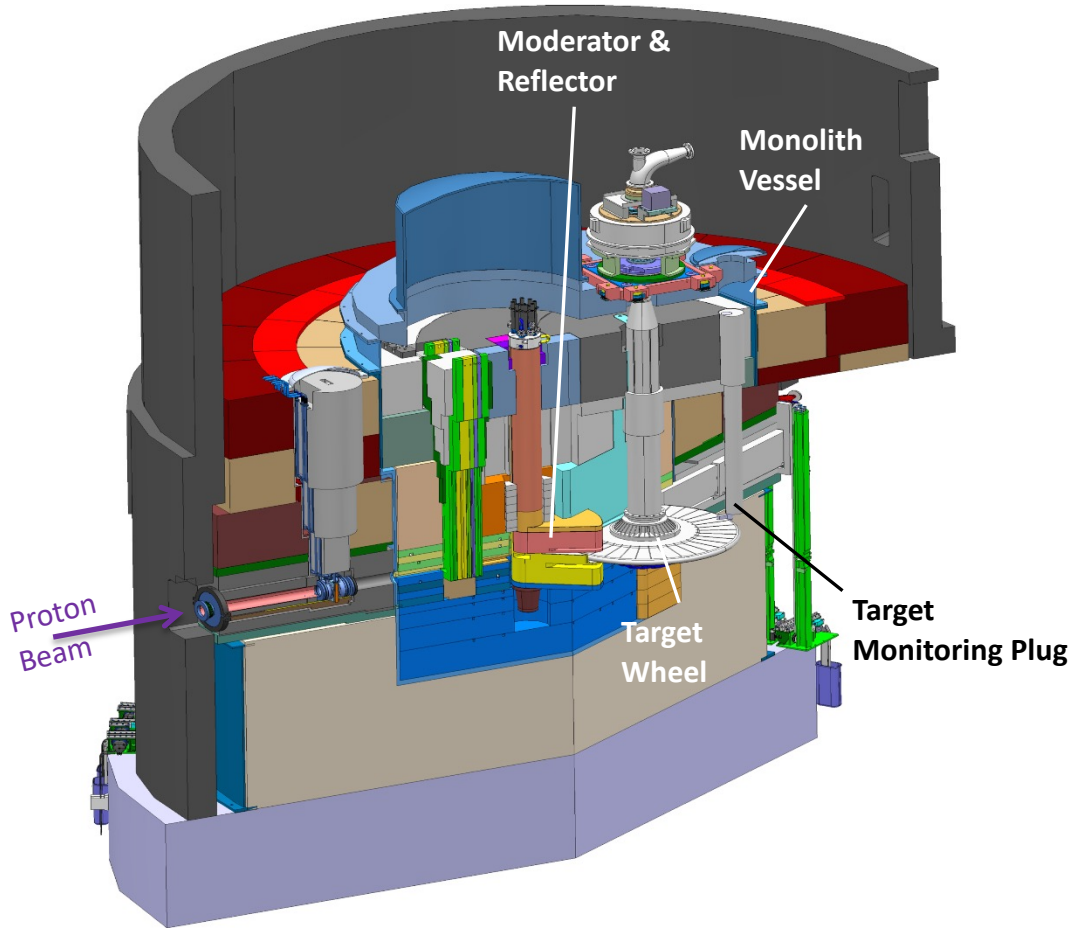
Current Status: Phase 3 of Beam Commissioning



Current Status: Phase 3 of Beam Commissioning



Target System and Moderator & Reflector



System

- *Rotating Target Wheel*
  - *36 sectors of solid tungsten, 11 tonnes*
  - *Rotates 23.3 rpm, synchronized with proton beam 14 Hz*
- *Moderator & Reflectors*
  - *Cryo-cooled*
  - *Mounted on rotatable pillar*
- *Monolith vessel vacuum*

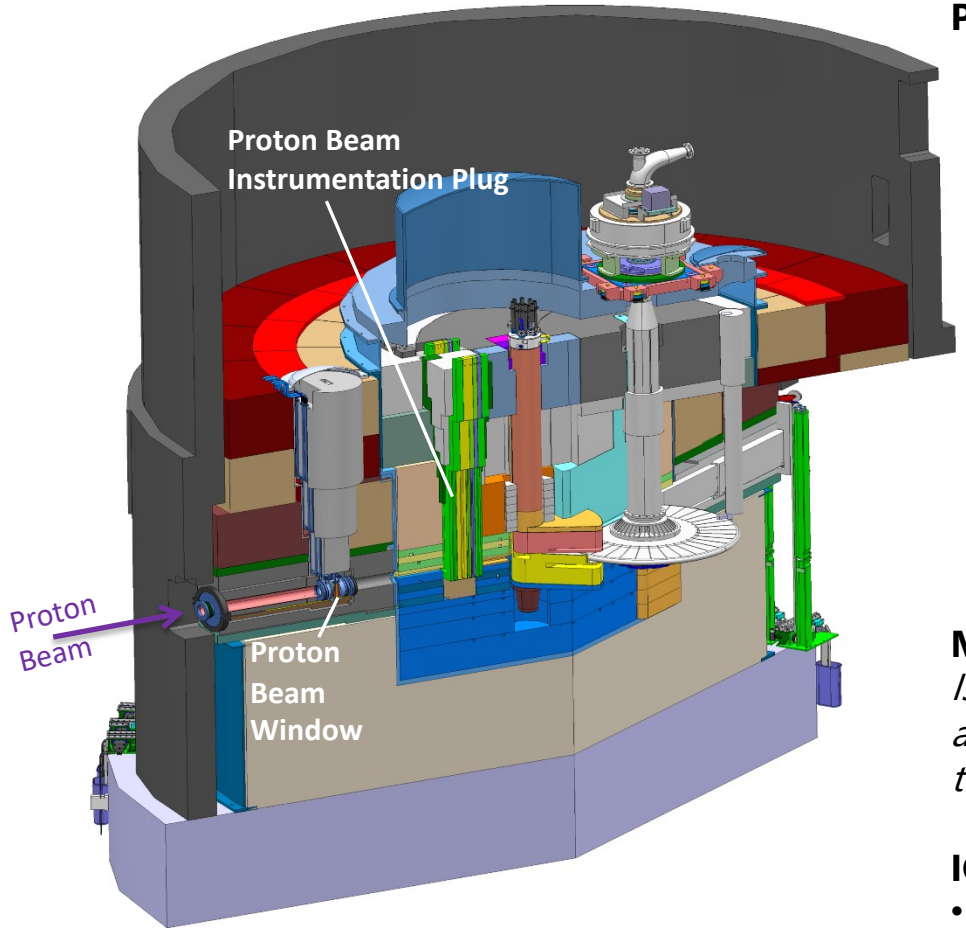
Main Functions

- *Neutron production*
  - *Align and synchronize sectors with proton beam*
  - *Moderate and reflect excited neutrons.*
- *Maintain vacuum*
- *Various monitoring functions*

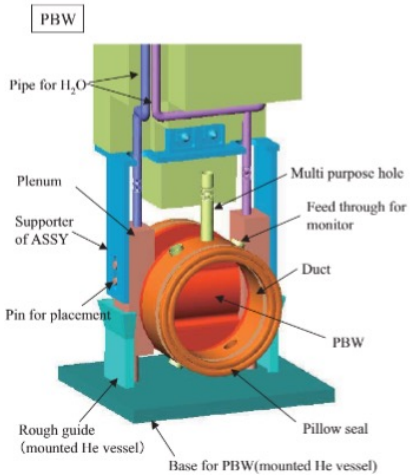
ICS Functions

- *Motion control, phase control/timing*
- *Lubrication control*
- *Monitoring of alignment, vibration, temperature, …*
- *Vacuum plant automation*

Proton Beam Window & Instrument Plug



Proton Beam Window



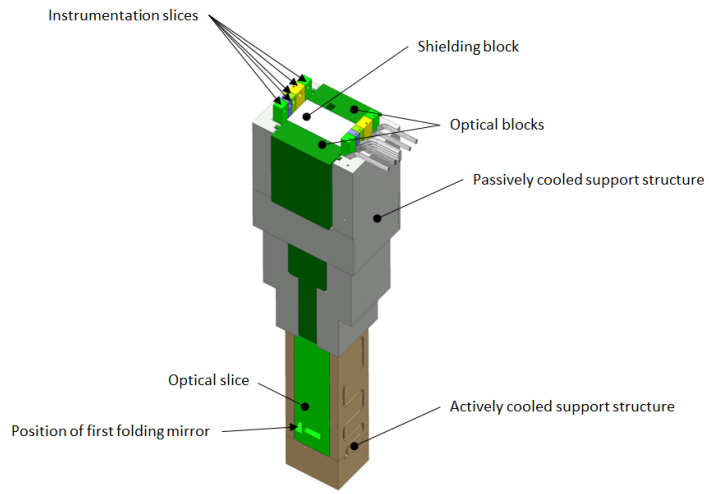
Main Function

Isolates high vacuum in accelerator from rough vacuum in the monolith.

ICS Function

- *Monitoring system*

Instrument Plug



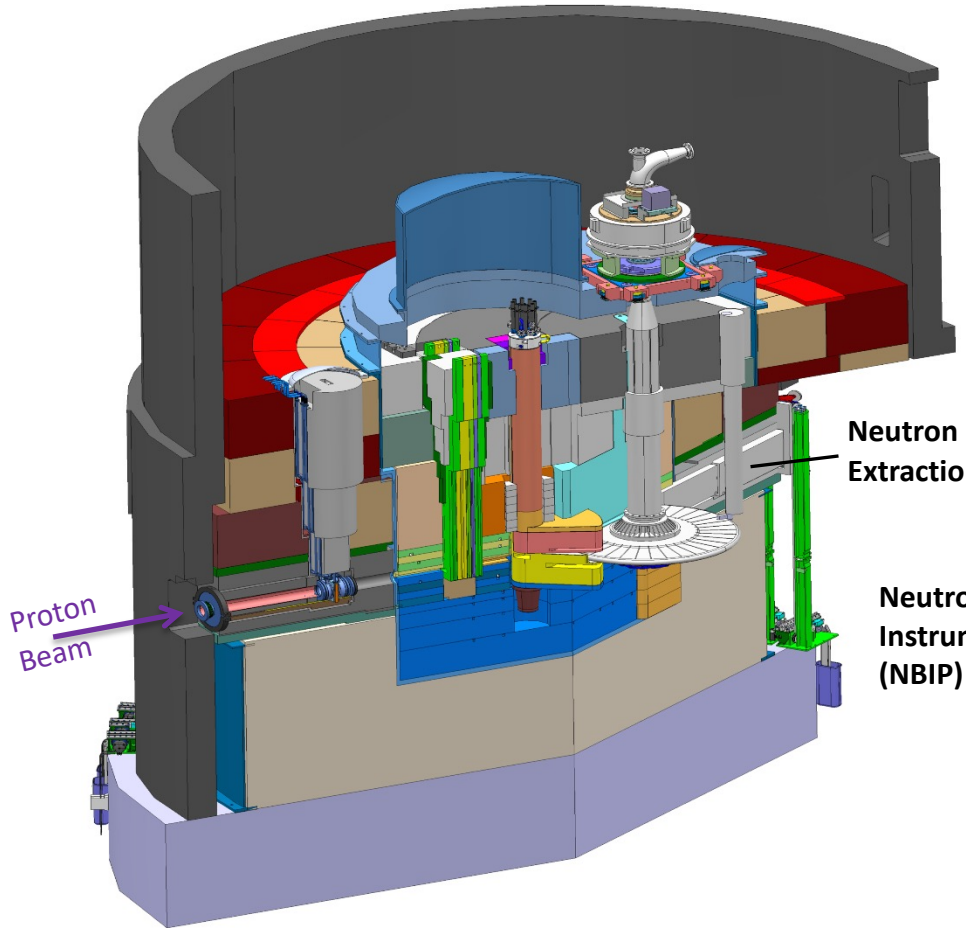
Main Function

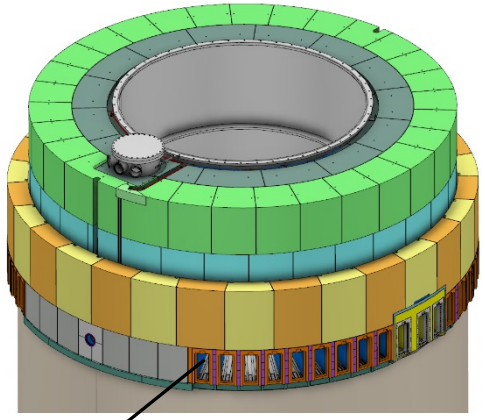
Supports the instrumentation slices containing Proton Beam Instrumentation.

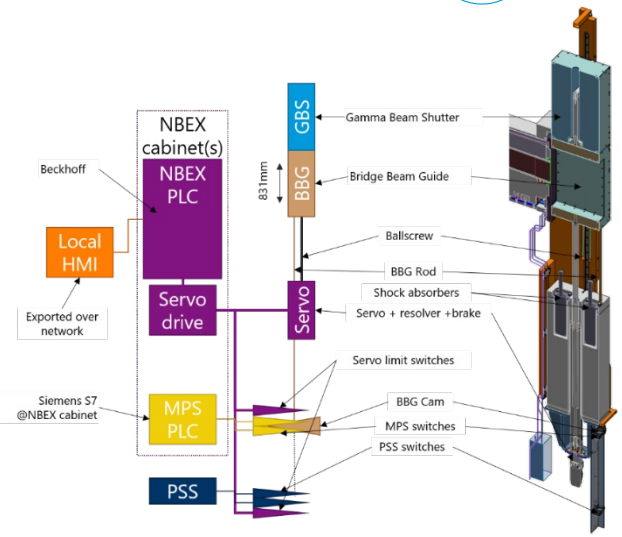
ICS Function

- *Cooling control*
- *Temperature monitoring*
- *Slice body deformation monitoring*

Neutron Beam Extraction (NBEX) and Light Shutters







System

- *16x light shutters*
- *Motion control instrumentation*
- *PSS interface*

Main Function

- *Align the beam optics when beam is on*
- *Shield bunker from gamma radiation when beam is off*

ICS Function

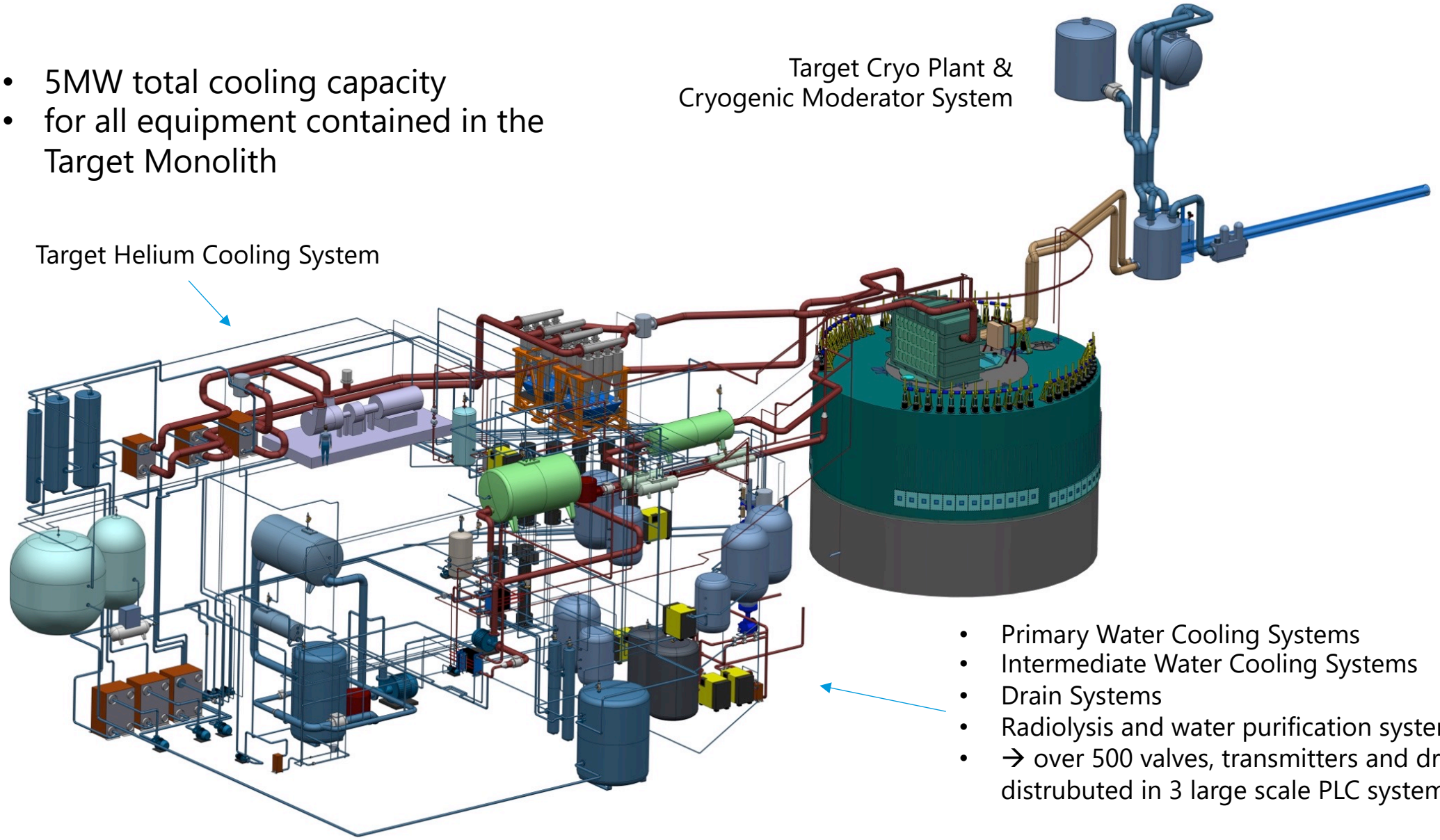
- *LSS Control System*
- *PLC with motion control logic for 16 axes*

Cooling Utility Plant

- 5MW total cooling capacity
- for all equipment contained in the Target Monolith

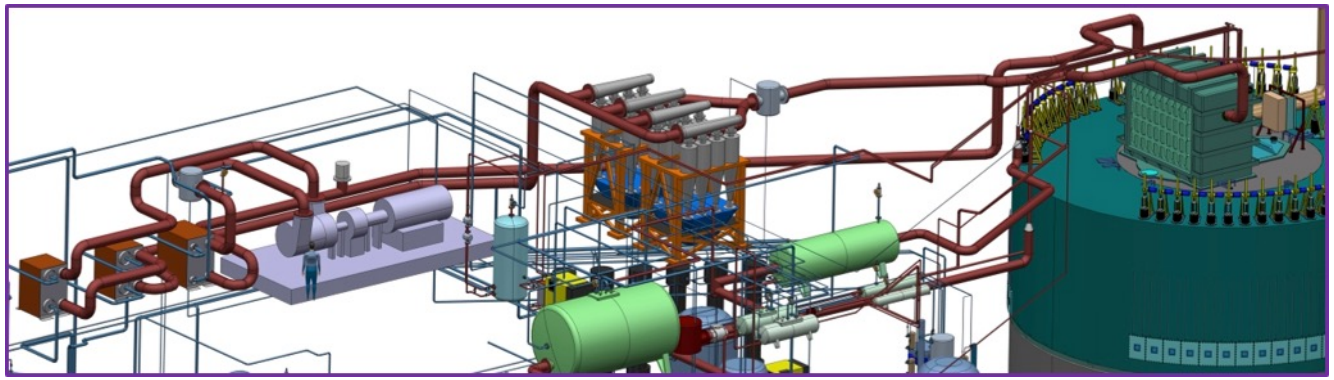
Target Cryo Plant &
Cryogenic Moderator System

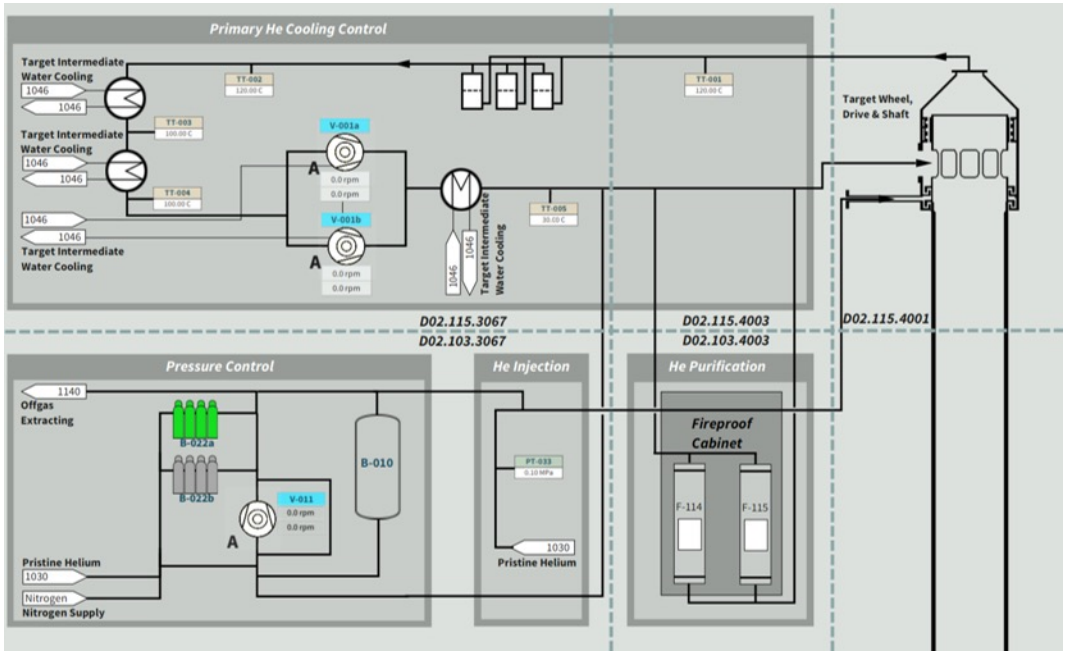
Target Helium Cooling System



- Primary Water Cooling Systems
- Intermediate Water Cooling Systems
- Drain Systems
- Radiolysis and water purification systems
- → over 500 valves, transmitters and drives distrubuted in 3 large scale PLC systems

Target Helium Cooling System





System

- *17kW Cooling Power, 20°K, 1000g/s*
- *Two turbomachinery circulators, valves*
- *Helium-water heat exchangers*
- *Temperature, pressure, flow sensors*
- *Helium supply systems*
- *Helium purification system*

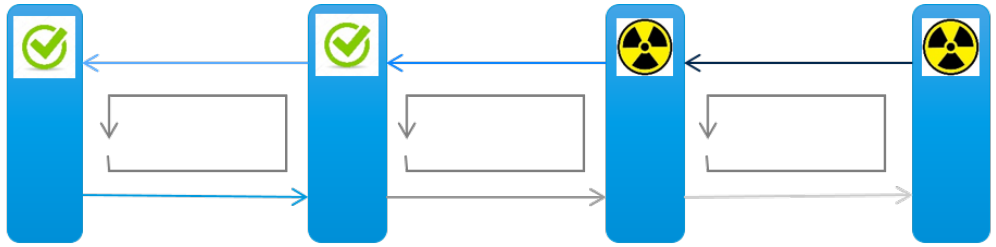
Main Function

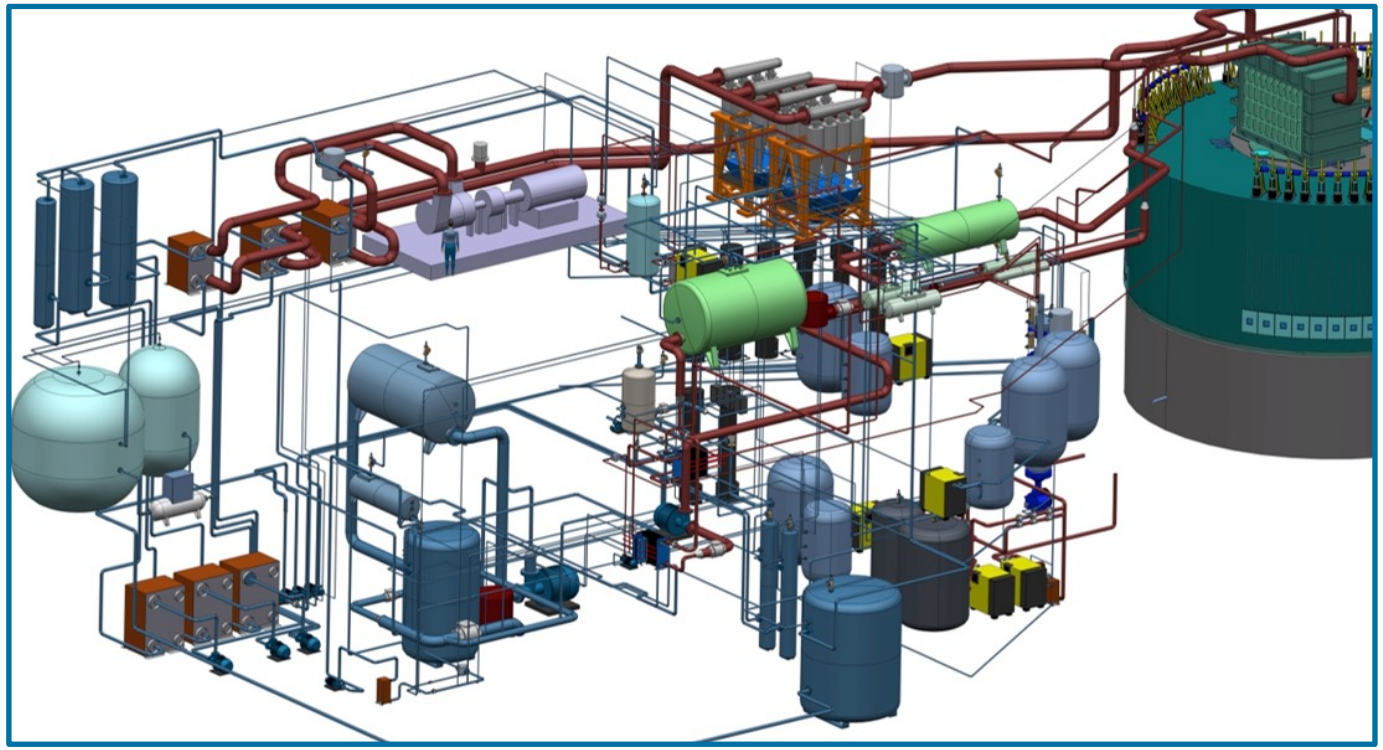
- *Cool the Target Wheel*

ICS Function

- *Target Helium Cooling Control System*
- *PLC-based control system*
- *Automation of:*
  - *Purging*
  - *Filling*
  - *Circulation*
  - *Overall operation*
- *Closed-loop control of temperatures, flow and pressure*

Water Cooling, Drainage & Radiolysis Systems





Systems

- *Primary Water Cooling System For Moderator (1041)*
- *Primary Water Cooling System For Reflector (1042)*
- *Primary Water Cooling System For Shielding & Plugs (1043)*
- *Intermediate Water Cooling System For Moderators & Reflectors (1044)*
- *Intermediate Water Cooling System For Shielding & Plugs, and Radiolysis (1045)*
- *Intermediate Water Cooling System For Helium (1046)*
- *Radiolysis System (1040)*
- *Water Drainage System (1047)*

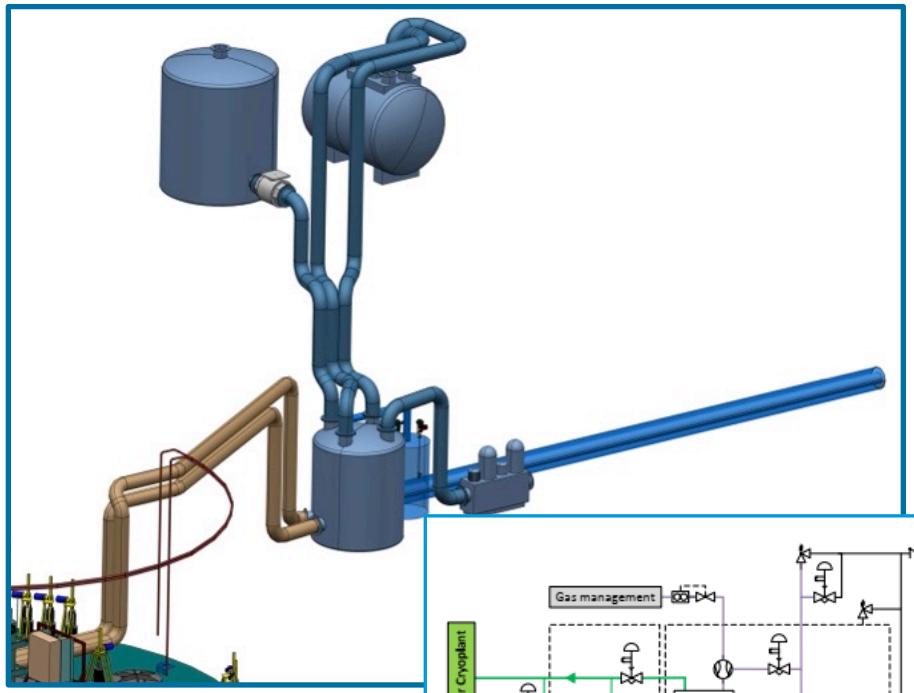
Function

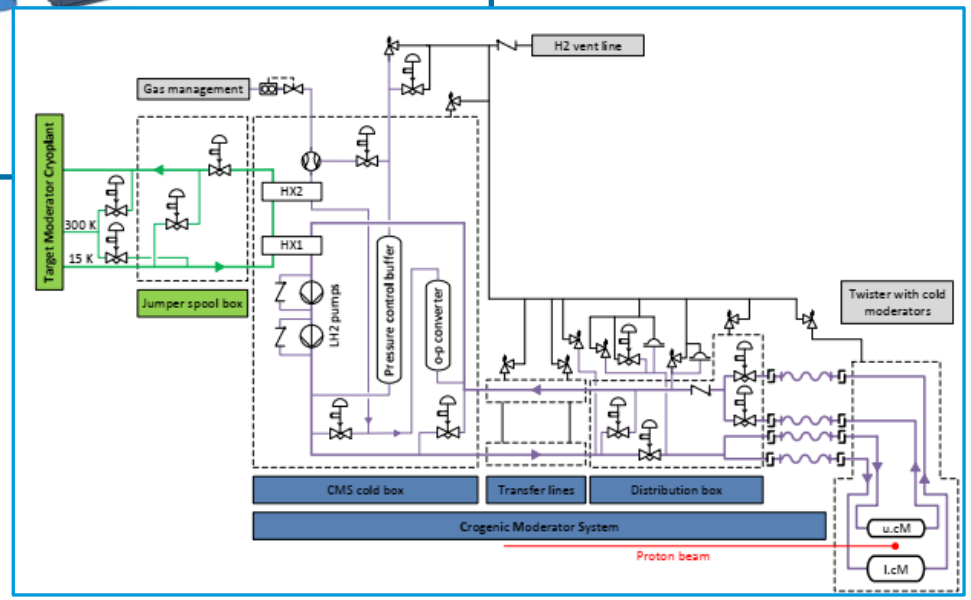
- *Heat removal → Water-cooling*
- *Drainage, recycling and purification*

ICS Function

- *Multiple water cooling control systems*
- *PLC-based controllers*
- *Automation of the operation concepts*
- *Closed-loop control*

Cryogenic Moderator System





System

- *Unique cryo system*
- *Cooling Power 17KW (neutronic heat)*
- *Temperature 20°K*
- *Flow 1000g/s*

Main Function

- *Provides cryogenic hydrogen to the cold moderator vessel*

ICS Function

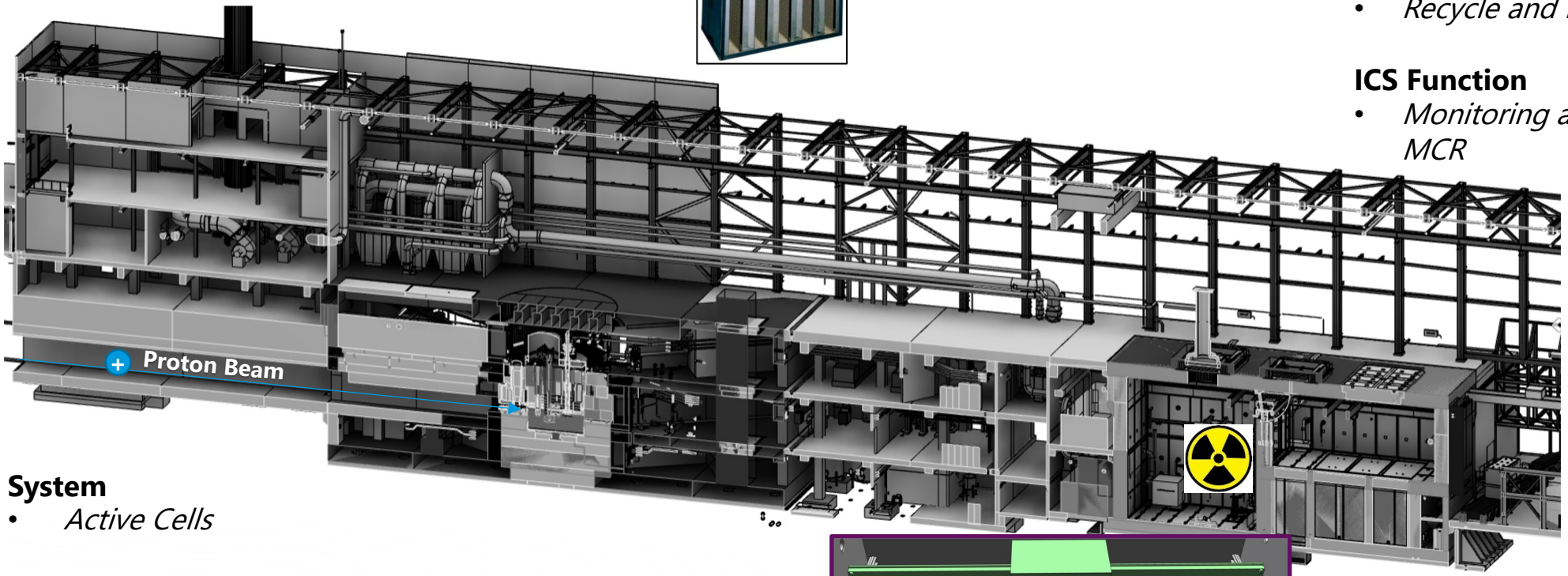
- *CMS Control System*
- *PLC-based*
- *Automation of complex processes:*
  - *Nitrogen purge*
  - *Hydrogen filling*
  - *Startup, hydrogen cool down to 20°K*
- *Closed-loop control of various process variables*

Other facilities of Target Building

System
- *HVAC*
- HEPA filters, 3000 m3/h

Main Functions
- *Maintain negative pressure inside building*
- *Recycle and filter the air*

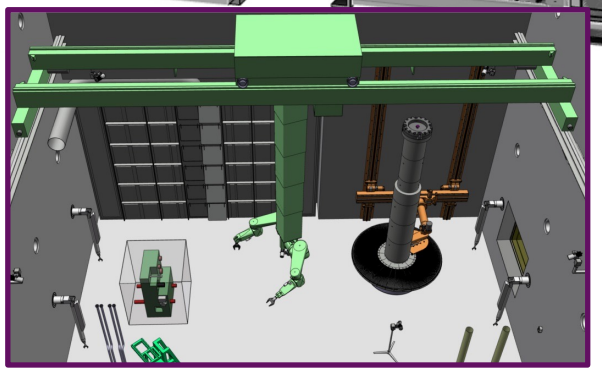
ICS Function
- *Monitoring and integration into MCR*



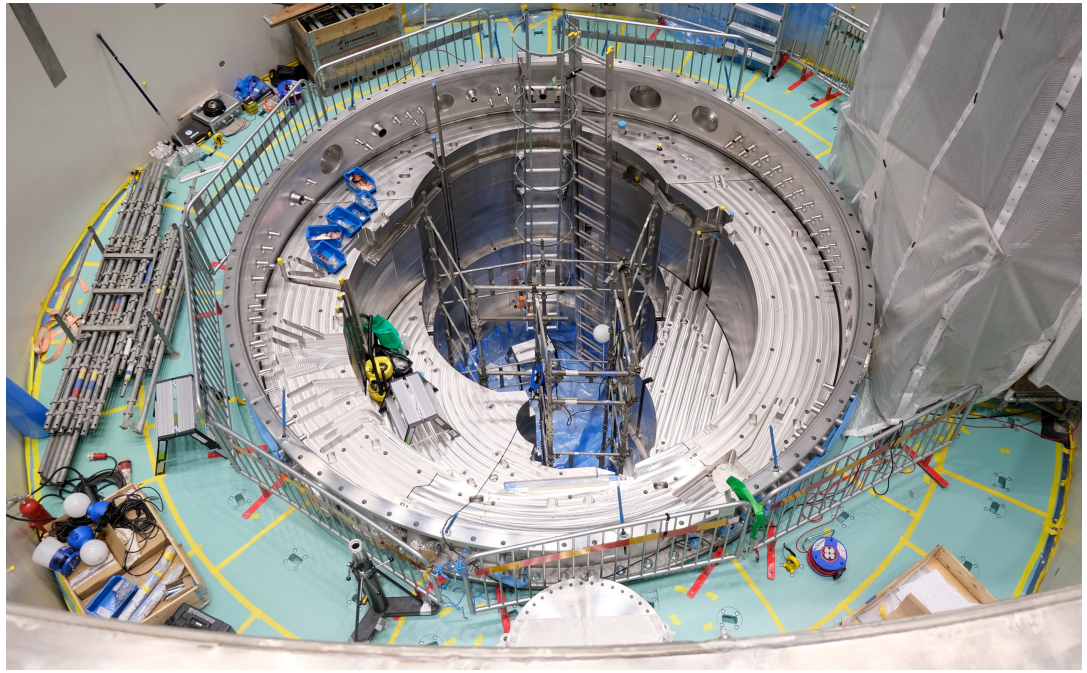
System
- *Active Cells*

Main Function
- *Decommissioning of activated equipment.*
  - *Confined Storage and Remote Handling Systems.*
  - *Robotic cutting machines, CCTV monitoring, VR*

ICS Function
- *Monitoring of Active Cells Facility safety system status.*



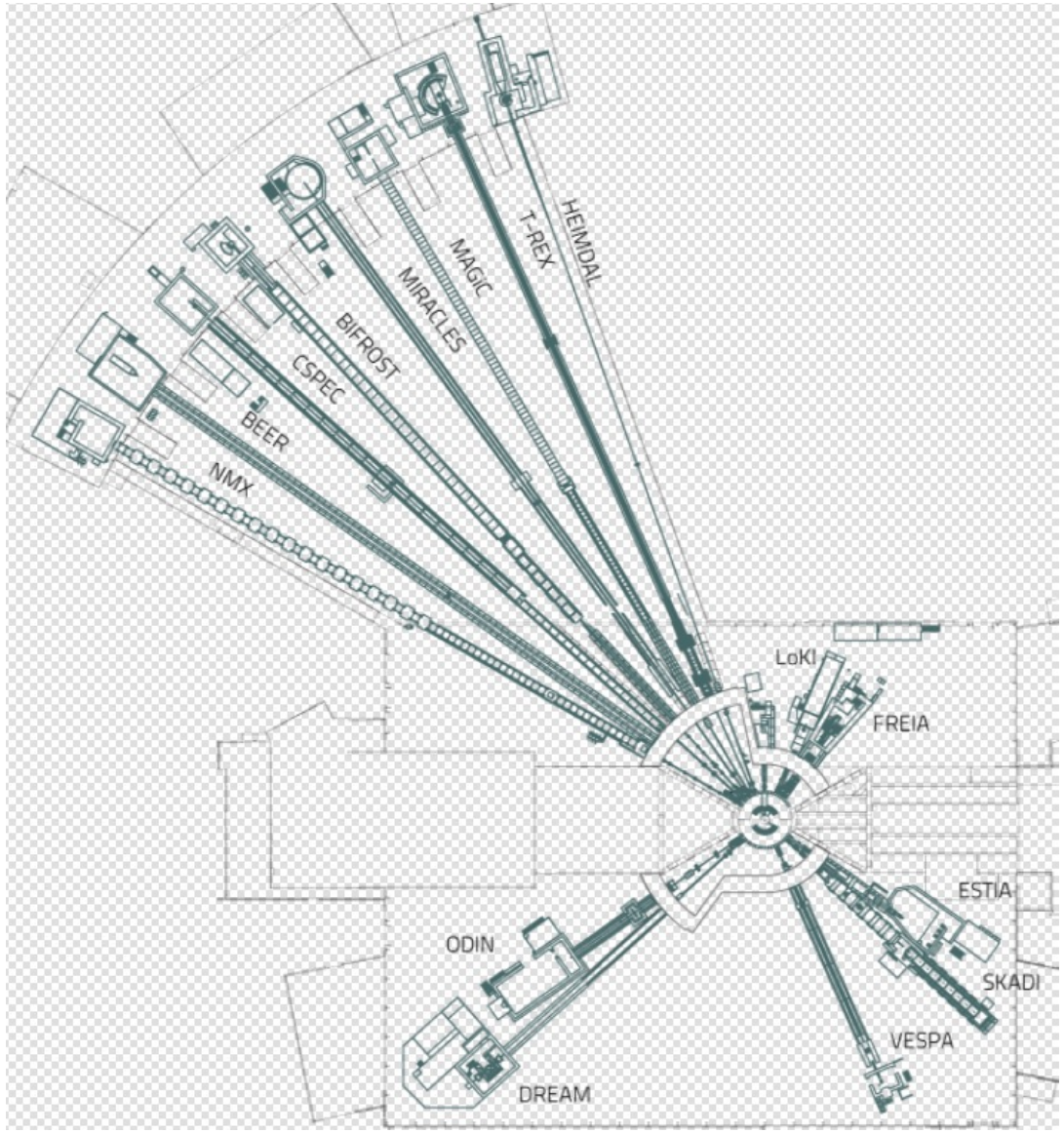
Target Construction



Birds eye view of Target Monolith.

Neutron beam windows from outside the bunker

Neutron Instruments

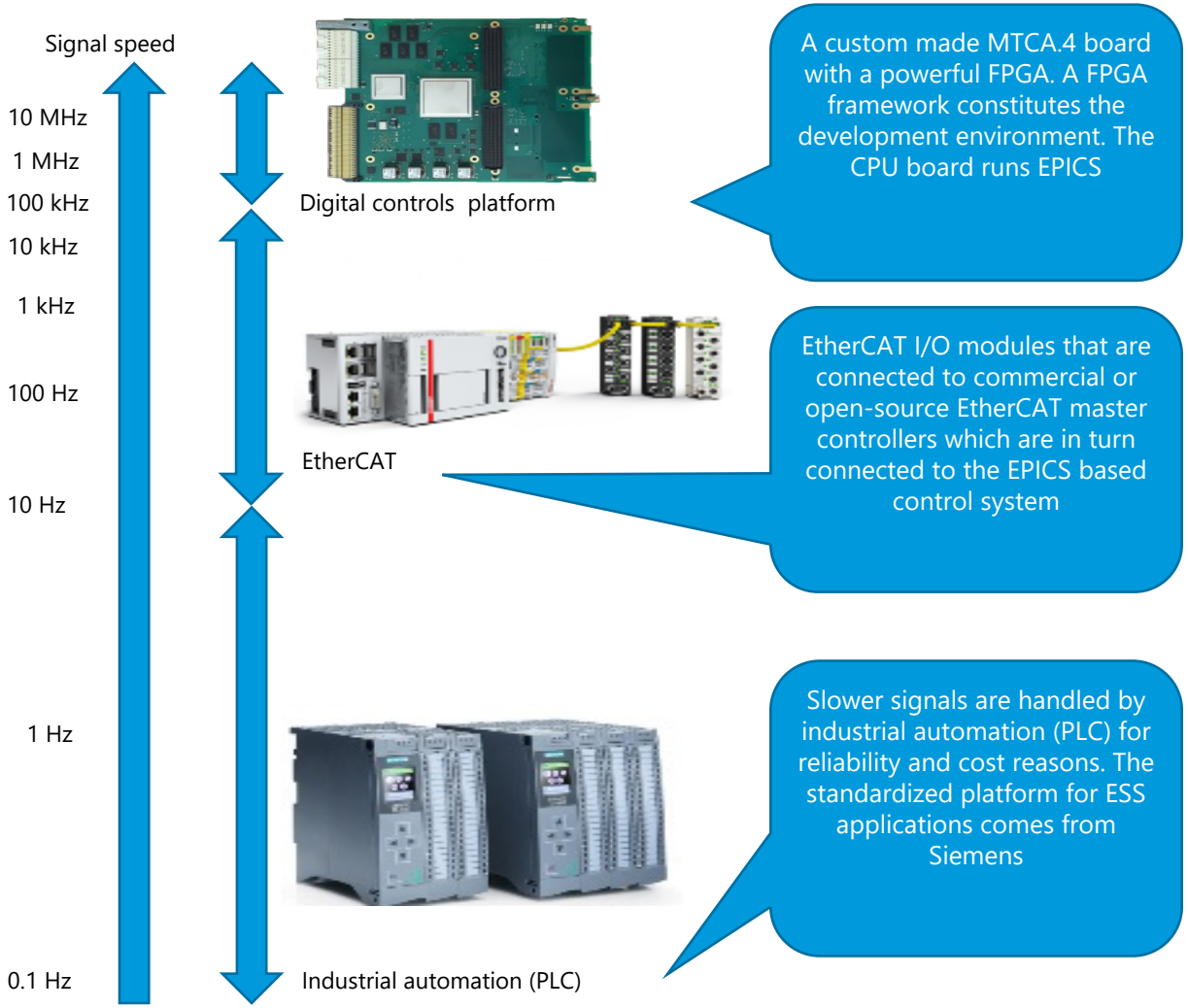


Proton pulse
14Hz base frequency

2027
16 beam lines: LOKI, ODIN, DREAM, BIFROST, etc.

Neutrons serve as a unique probe for revealing the structure and function of matter from the microscopic down to the atomic scale.

Three layer strategy for control system hardware at ESS



ICS has adopted a three layer strategy for implementing the control system based on signal processing needs

- MTCA.4 for applications with data acquisition exceeding ~100 kHz
- These applications require a FPGA and custom, high-speed signal processing in system.

- For slower signals, EtherCAT will be used as a real-time fieldbus with good price/performance ratio
- Synchronization and event information are key for applications where a full custom platform solution would be too costly
- Can also run on MTCA platforms

- Low speed signals are handled with commercially available PLC systems
- This is a cost-effective solution that addresses ESS reliability and maintainability requirements
- The PLCs are connected to EPICS for further integration into the control system

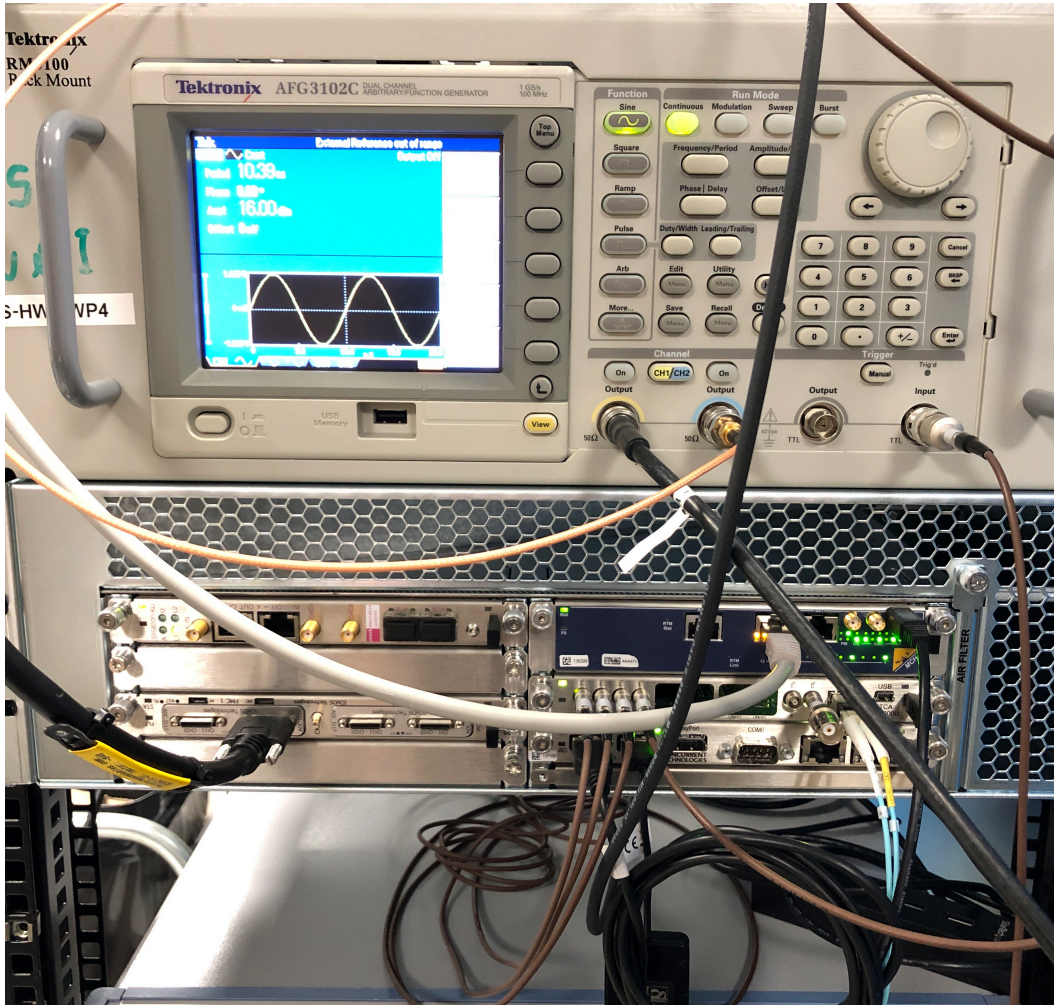
Hardware Integration

The deployment of many systems

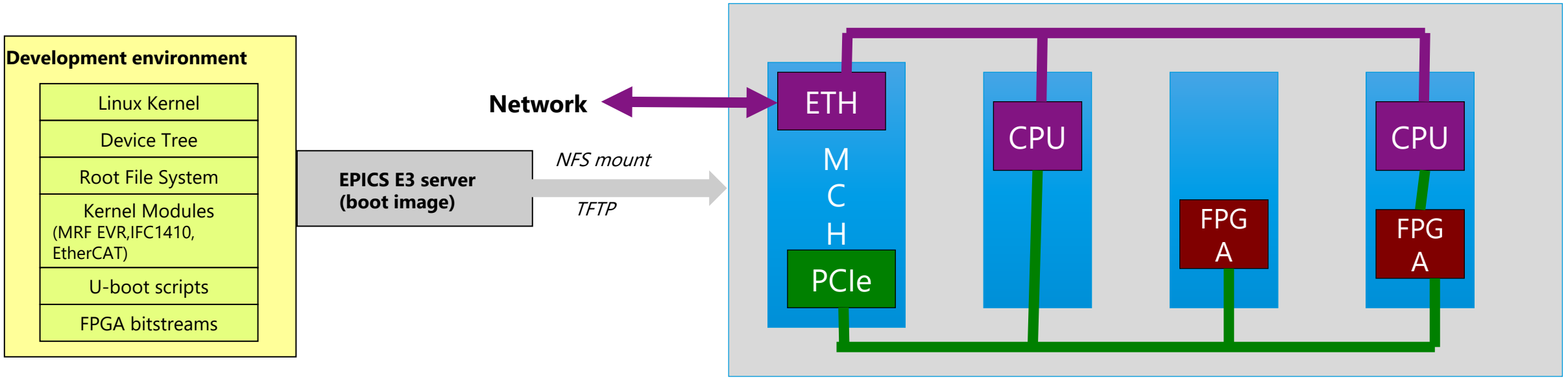
The integration of all the different systems used at ESS into the controls environment is a big task and involves control systems.

Use of MicroTCA for the fast data acquisition systems is helping to drive ESS's push for technical excellence. Over 200 systems will be deployed throughout the facility.

This is where having a functional IPMI manager is a huge asset to the control room operators!



MicroTCA software&firmware architecture



Multiprocessing architecture: mixture of central + AMC on-board CPUs

- not all features established yet, though…

Operating System(s): Linux Yocto, or CentOS (soon to be replaced) with real-time capability

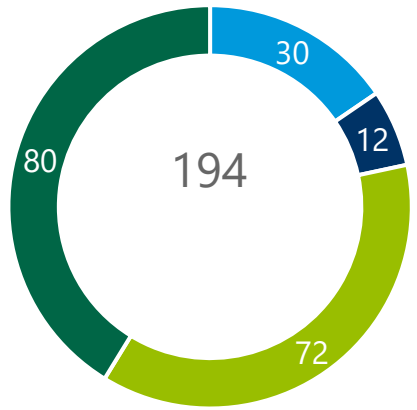
- EPICS on either a central CPU, on the AMC (IOxOS) IFC local CPU, or both (scalability, application-specific processing)

All software/firmware modules are in GitLab repositories

- All updates of e.g., kernel modules or new FPGA firmware versions

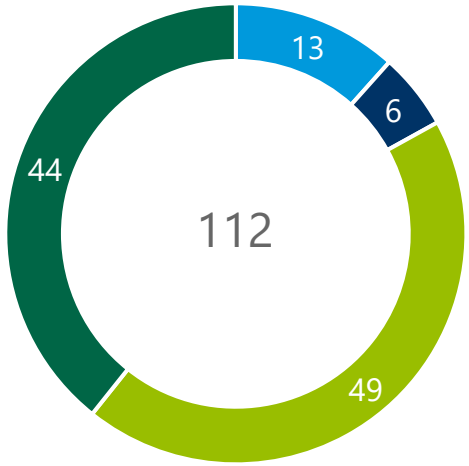
Deployment of MicroTCA at ESS

Total Crate Deployment for First Science 2.5kW Neutron Beam



Timing Distribution System
Machine Protection Systems
Beam Instrumentation
RF

Current Installed Systems



Timing Distribution System
Machine Protection Systems
Beam Instrumentation
RF

Novel diagnostics: neutron Beam Loss Monitor MTCA

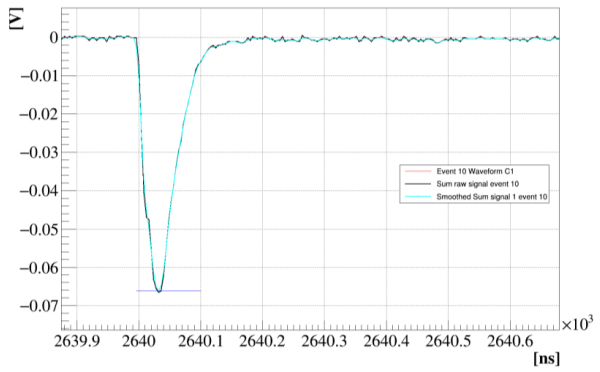
Beam Loss Monitors using neutron detection

- Collaboration of CEA (France), Lodz University of Technology (Poland) and ESS

Based on Micromegas detectors

Fully digital signal processing

- 250 MSPS data acquisition, processing on FPGA

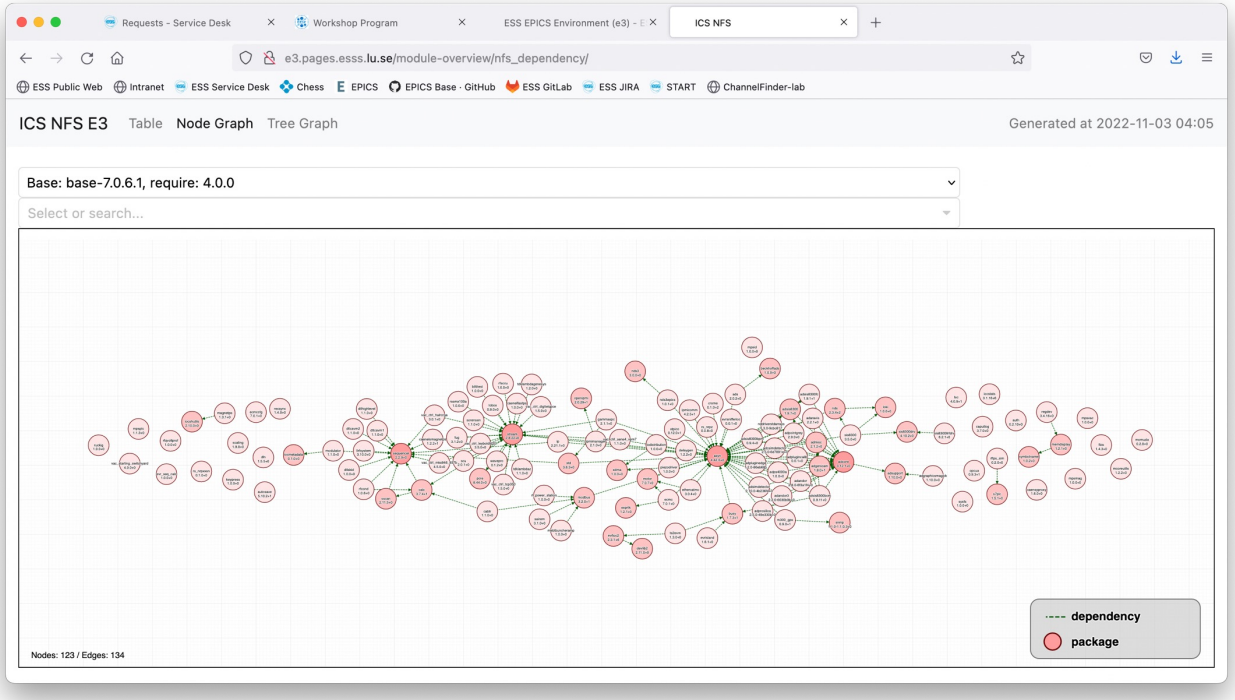


Control system development and deployment

A lot of work has been done with our EPICS development environment (E3)

- The environment is centrally provided for all (production) systems/IOCs
  - EPICS Core release, in multiple (but limited number of) versions
- IOC is configured start-up time
- IOCs become “codeless” – startup scripts plus database configuration
  - Module updates (in an individual IOC) do not require compilation
- Automated builds with GitLab CI

In stable production use



Module viewer – a helper tool for developers

- Shows EPICS modules (device support, etc.) and dependencies between them
- At the moment, 123 modules provided

ESS Linux Distribution

- YOCTO Project version Dunfell 23.0.21+ - Linux 4.14
- The objective is to provide a minimal system for running EPICS IOCS and in middleware.
- Supports:
  - Concurrent AMG6x/AM900 (Intel XEON/ Core-i7 64-bit)
  - IOxOS IFC14xx (NXP QorIQ PowerPC 64-bit)
  - Both systems are supported also with real time Linux.
- We also provide users with a small amount of tools for test and debugging natively.

Next Steps

Continue commissioning until Sept. for the Normal Conducting Linac

Initial deployment of AXI based framework for the IOxOS based systems

2024 commission of the Super Conducting Linac, up to the beam dump.

Begin roll-out of Yocto based ESS Linux OS

2025 First Beam on Target

2027 Start of First Science and preliminary scientific papers published.

2027 -> Continue opening of additional beam lines up to first 15 instruments.

Finish presentation