Status of the European Spallation (Neutron) Source

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on behalf of the Target Design Team,
including In-Kind Partners

Presented at IWSMT-13

www.europeanspallationsource.se

October 31, 2016

Outline

- ESS Project Overview
- Target Sub-Project Overview
- Target wheel
- Moderator-reflector plug
- Monolith vessel atmosphere
- Concluding remarks

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ESS aims to be the brightest neutron source in the world

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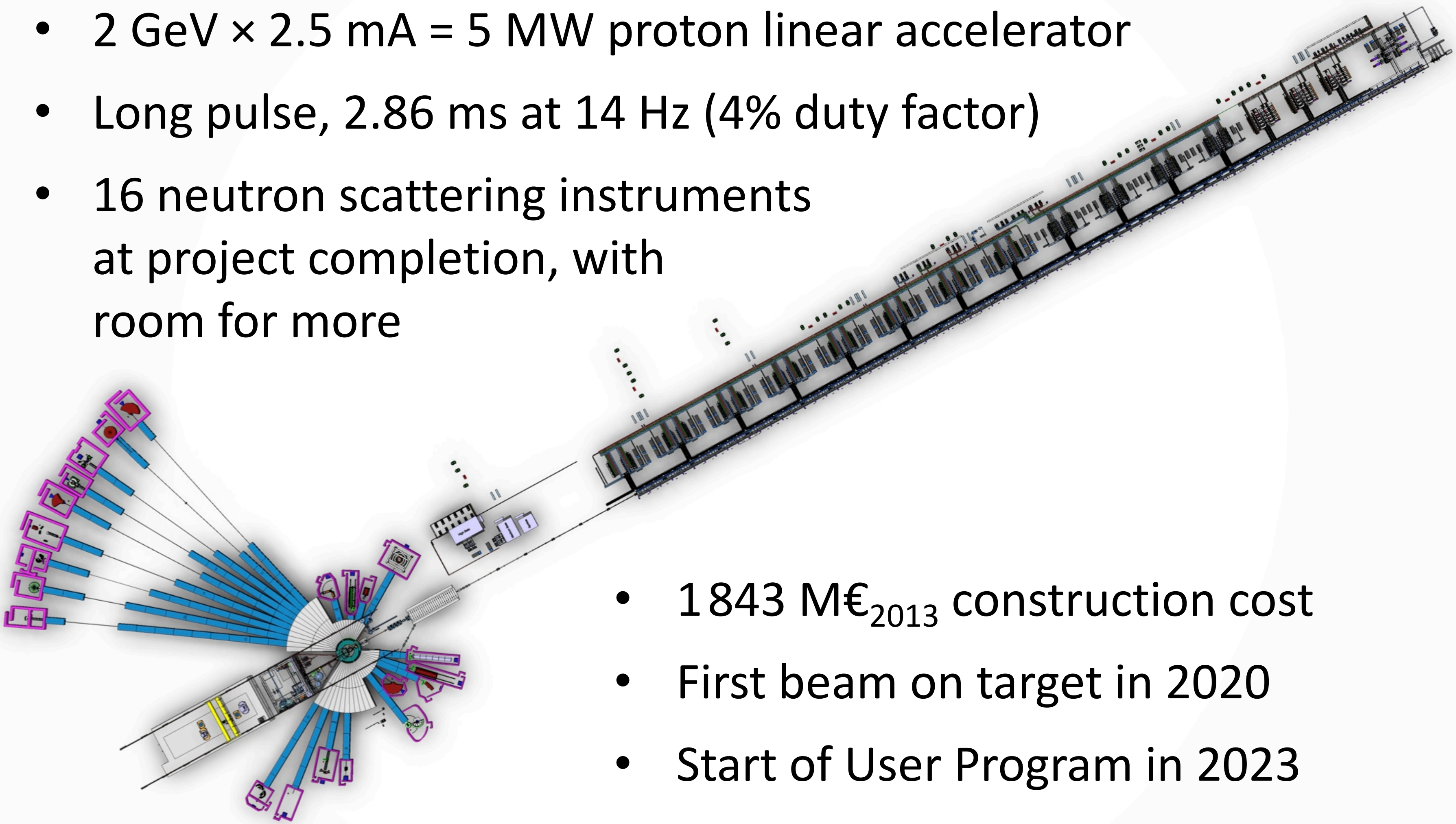
- 2 GeV × 2.5 mA = 5 MW proton linear accelerator
- Long pulse, 2.86 ms at 14 Hz (4% duty factor)
- 16 neutron scattering instruments at project completion, with room for more



- 1843 M€$_{2013}$ construction cost
- First beam on target in 2020
- Start of User Program in 2023

There is broad European contribution to the construction of ESS

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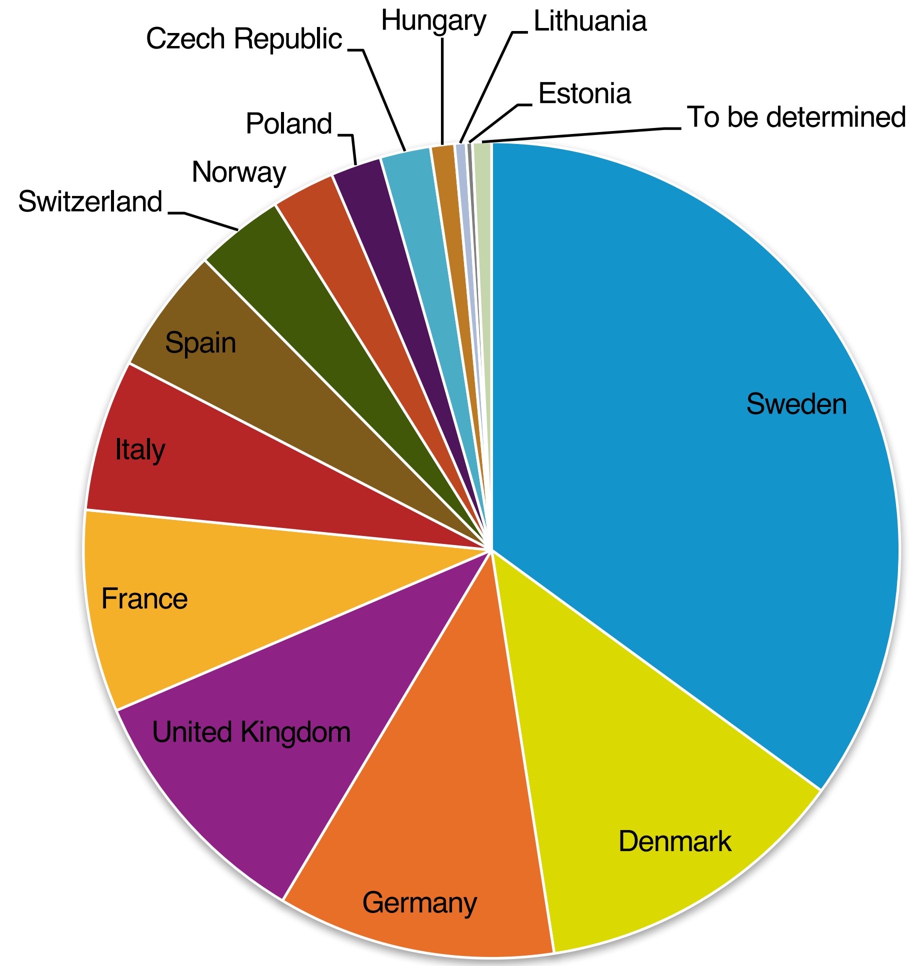
CURRENT

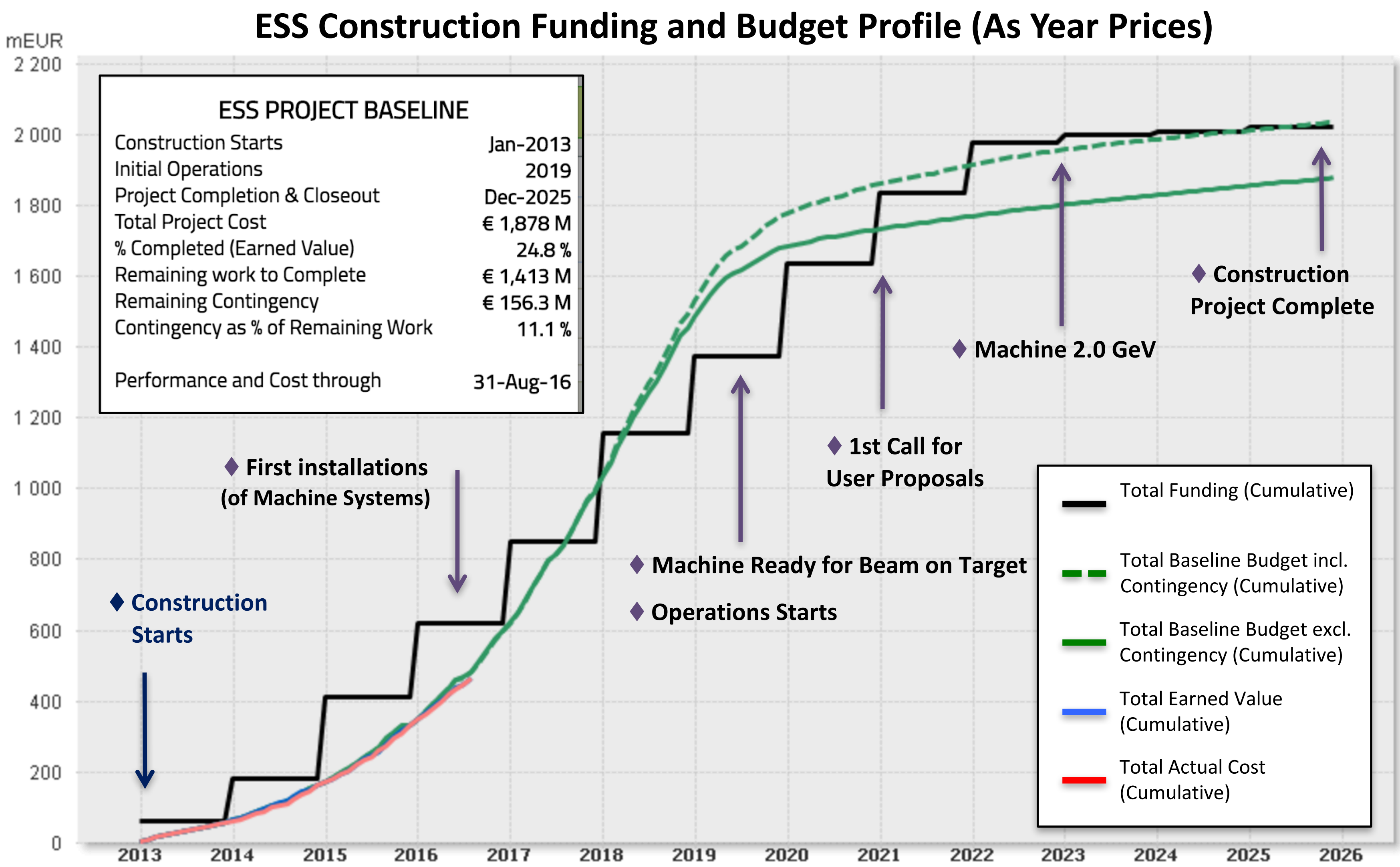
Sweden (member)	**35.0 %**
Denmark (member)	**12.5 %**
Germany (member)	**11.0 %**
United Kingdom (founding observer)	**10.0 %**
France (member)	**8.0 %**
Italy (member)	**6.0 %**
Spain (founding observer)	**5.0 %**
Switzerland (member)	**3.5 %**
Norway (member)	**2.5 %**
Poland (member)	**2.0 %**
Czech Republic (member)	**2.0 %**
Hungary (member)	**0.95 %**
Lithuania (future member)	**0.45 %**
Estonia (member)	**0.25 %**
Total (minus preconstruction)	**~97 %**

FUTURE

Belgium (founding observer)	*tbd*
Netherlands (founding observer)	*tbd*
Greece (future observer)	*tbd*
Turkey (future observer)	*tbd*
Latvia, Portugal, Finland	*tbd*

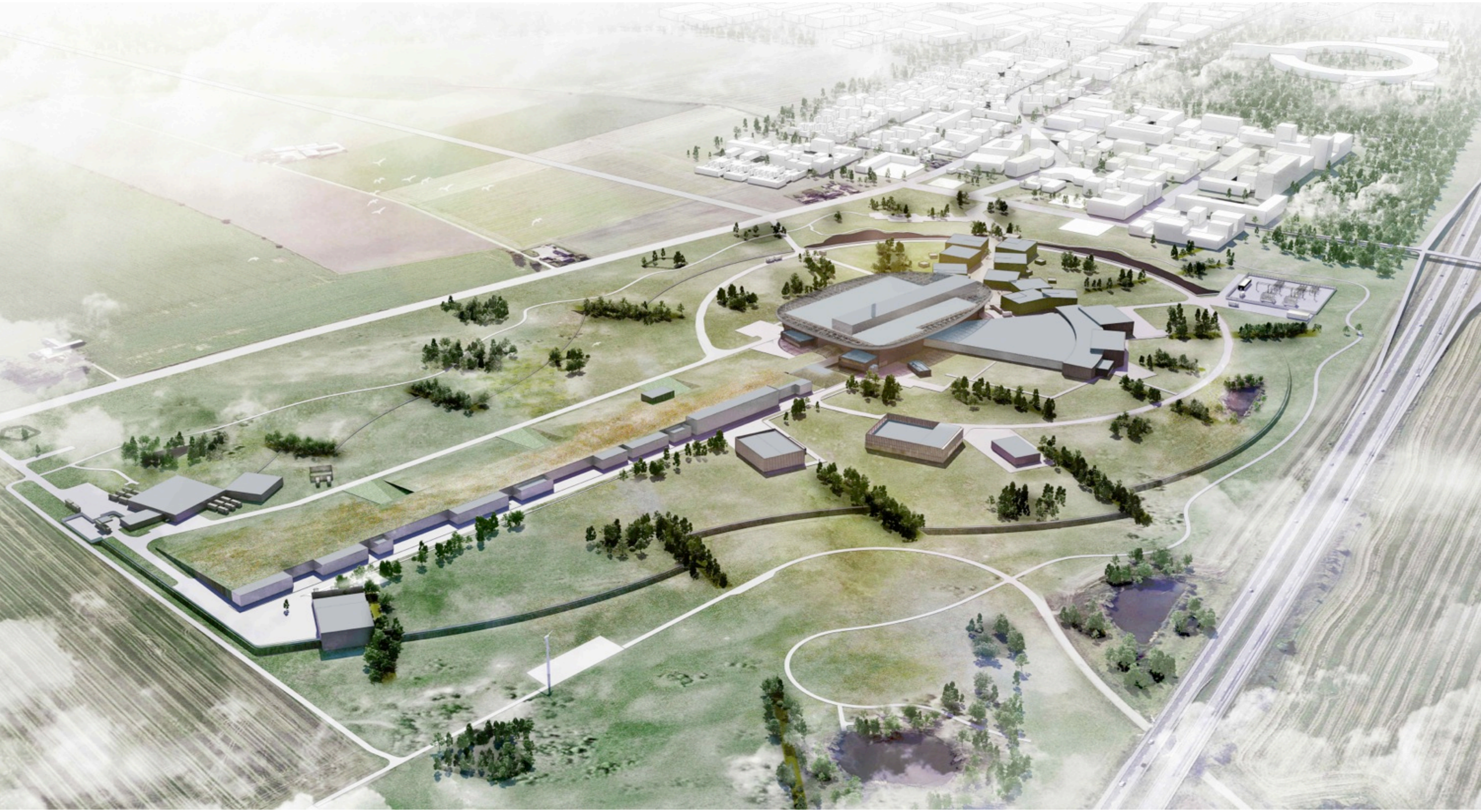


Construction is proceeding accroding to the project plan



Aerial View – August 2016

ESS looking towards MAX IV (in 2026)



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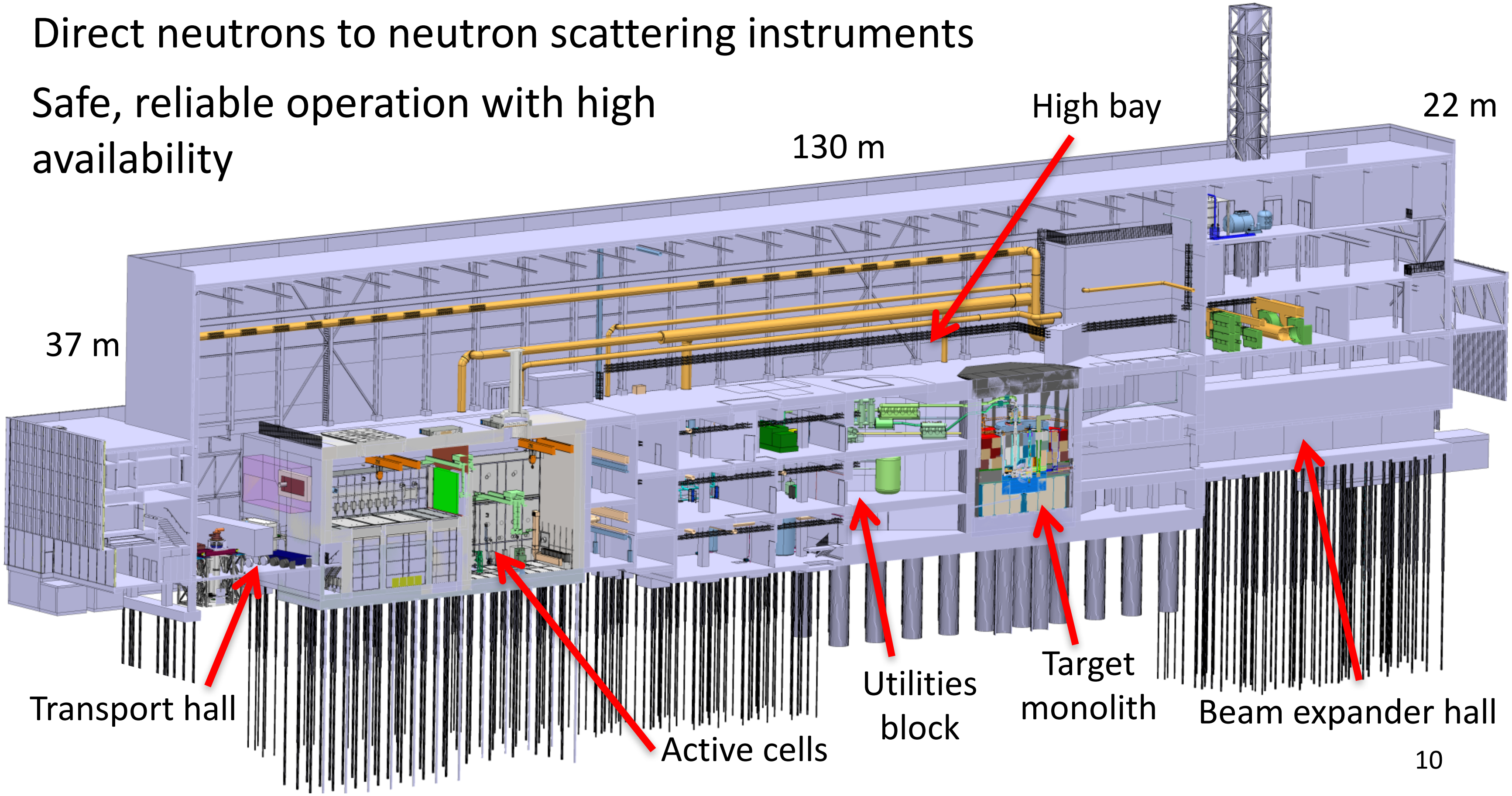
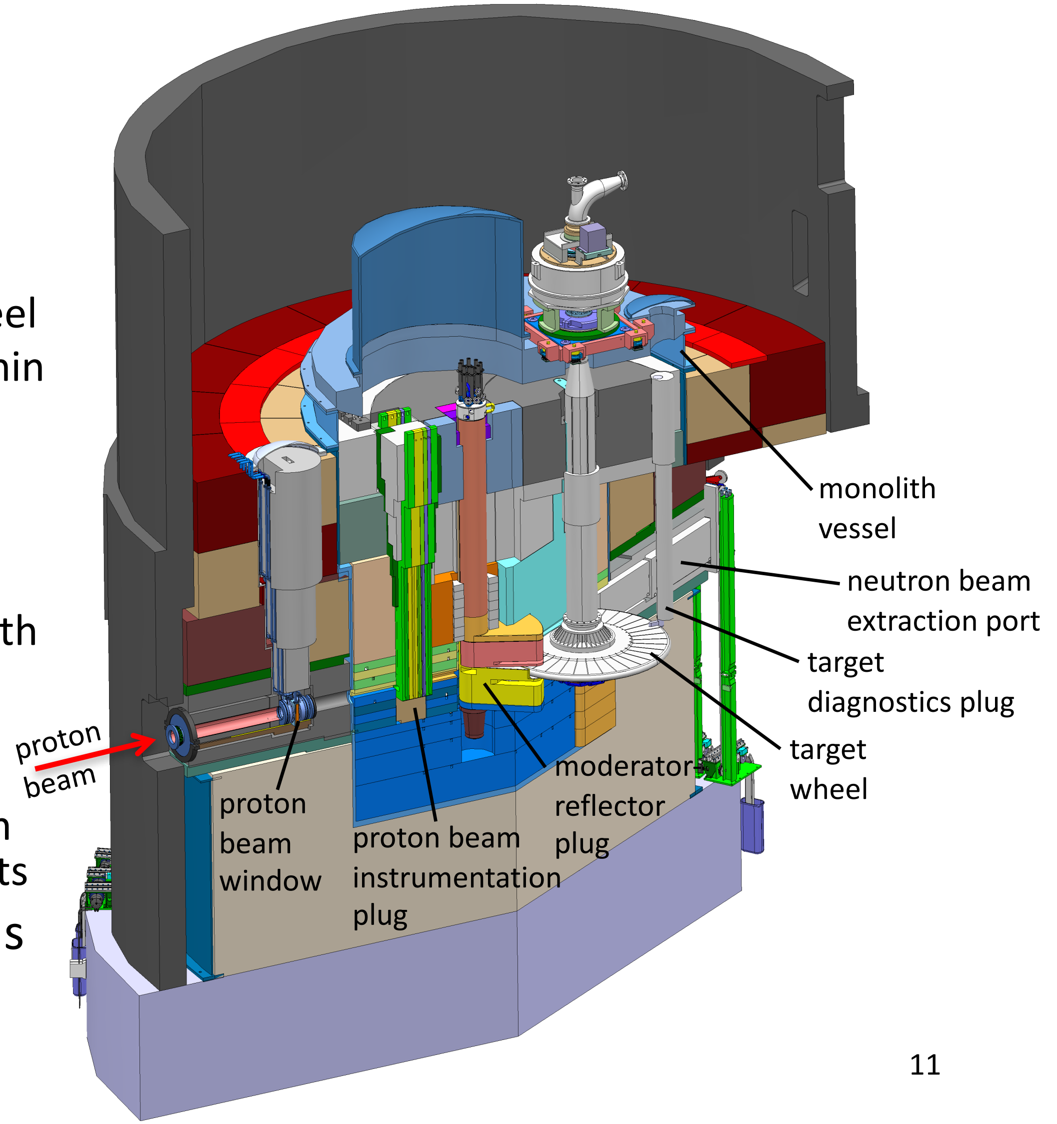
Target Station High Level Functions

- Generate neutrons via nuclear spallation using protons from the accelerator
- Slow the neutrons to speeds useful for neutron scattering
- Direct neutrons to neutron scattering instruments
- Safe, reliable operation with high availability

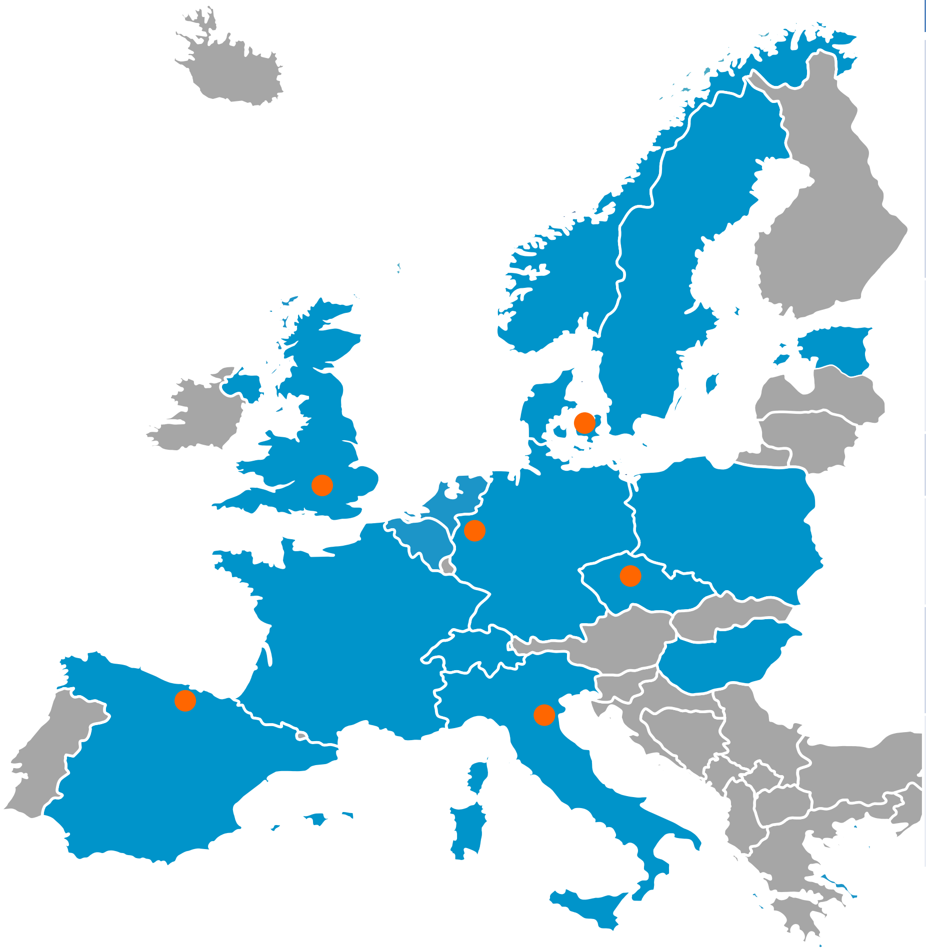


Target monolith and its internals

- The proton beam
  - Enters the monolith through a beam pipe
  - Passes through a proton beam window made of aluminum
  - Strikes the rim of the target wheel
  - Induces spallation reactions within the tungsten target material, producing copious neutrons
- The neutrons
  - Leak from the target wheel
  - Scatter into moderators filled with water and liquid hydrogen
  - Downscatter to low energies
  - Leak through neutron beam extraction ports that direct them to neutron scattering instruments
- Monolith is filled with 3000 tons of steel to shield high-energy neutrons from escaping



Six European partners contribute to the Target Station



Partner Institute:	Systems:
ESS Bilbao	Target wheel, proton beam window, proton beam instrumentation plug, monolith vessel, neutron beam windows, tuning beam dump
Forschungszentrum Jülich	Moderator-reflector plug, cryogenic hydrogen loop, cryogenic helium refrigerator
UKAEA-RACE	Active cells internals
Consiglio Nazionale delle Ricerche	Irradiation module
Technical University of Denmark	Tungsten release fractions
Czech Republic Nuclear Physics Institute	Target HVAC, primary and intermediate water systems, helium primary cooling system

Target building reinforcing bars in 2-m-thick base mat – August 2016

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Target – Hot cell, Utility & Monolith

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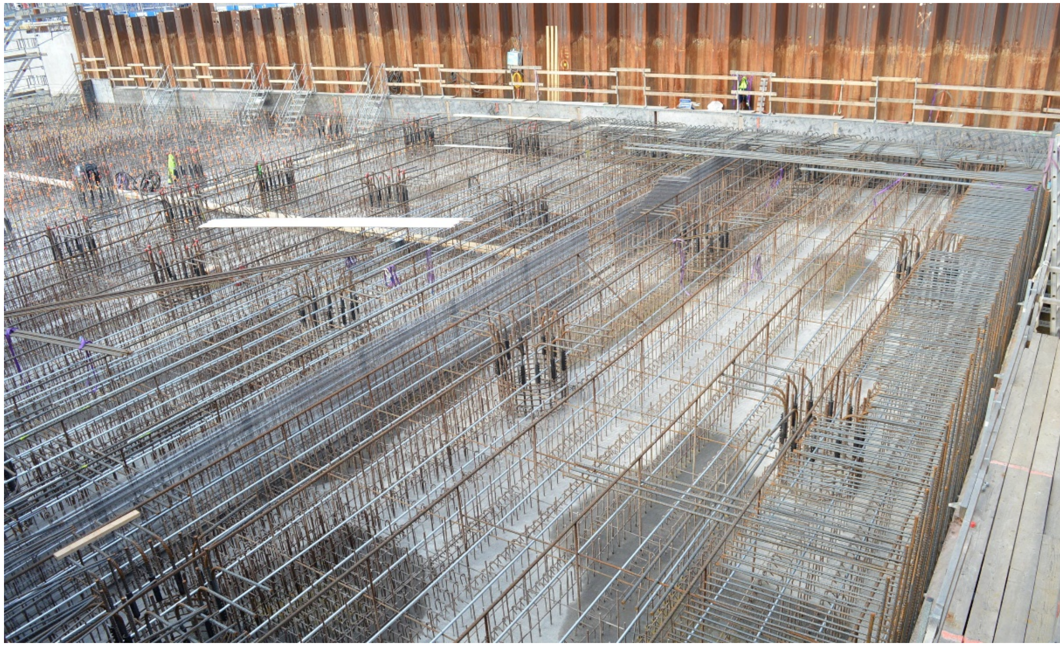

Reinforcement works, 1600 mm bottom slab, Monolith.
First casting: September 28.

Chip irradiation beam dump cavity now installed, ready for concrete pour

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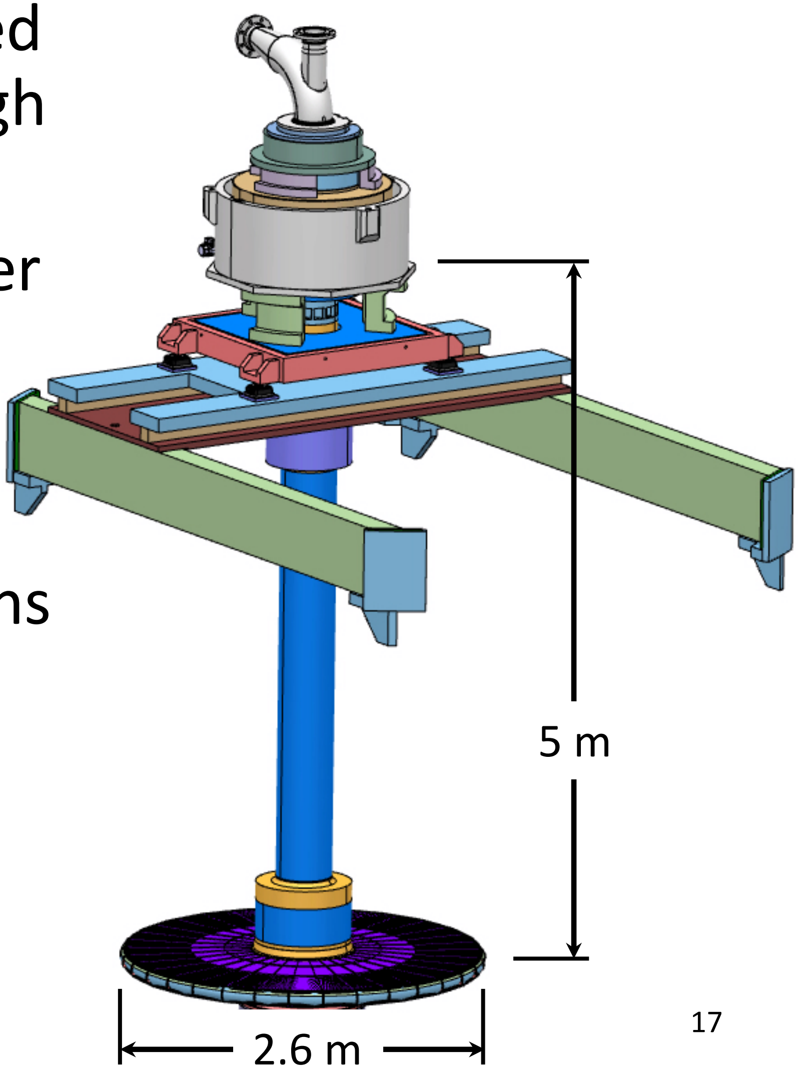
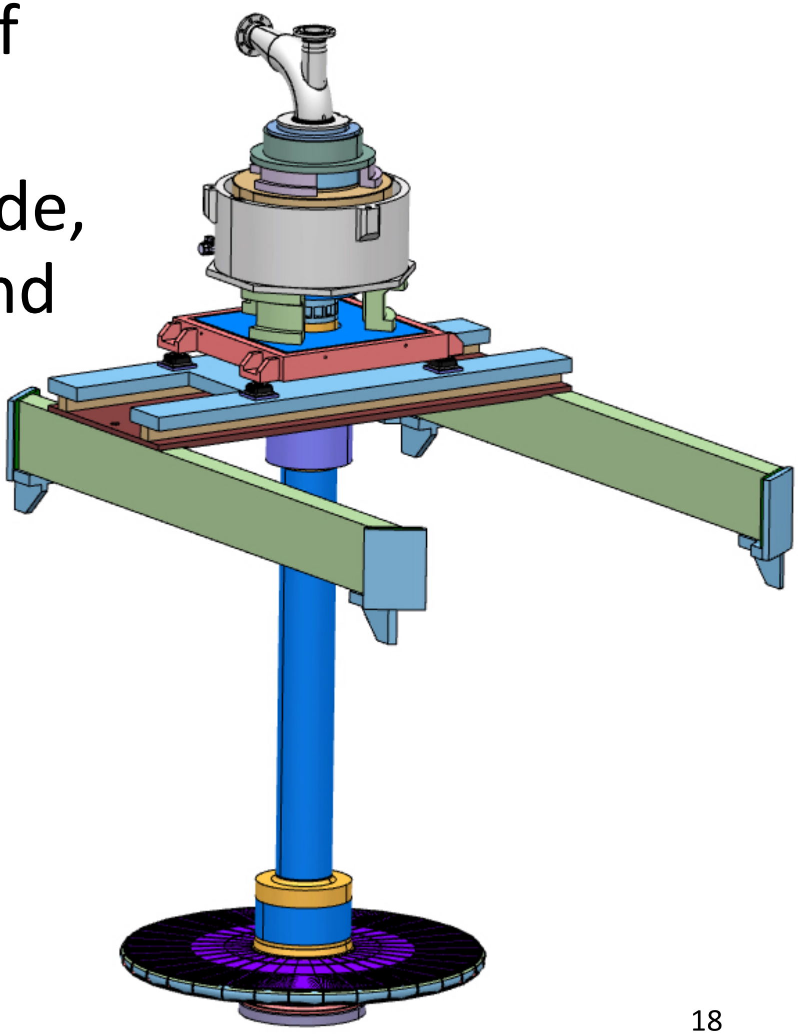
ESS will be the first spallation source to employ a helium-cooled rotating target

- Motor and bearings are mounted far away (5 meters) from the high radiation zone
- Wheel is suspended on a 6 meter long shaft
- Wheel contains 3 tons of tungsten
- Wheel+shaft total mass is 11 tons
- Helium removes 3 MW of heat deposited in the target by the 5-MW proton beam
- Expected lifetime of 5 years



Target wheel rotation scheme

- Target wheel has 36 sectors of 10° each
- The beam pulse is 2.86 ms wide, and pulses 14 times per second
- The target rotates such that each beam pulse strikes the center of a new sector
- Wheel rotation speed is then 14 Hz/36 = 0.39 Hz, or 10° between each pulse



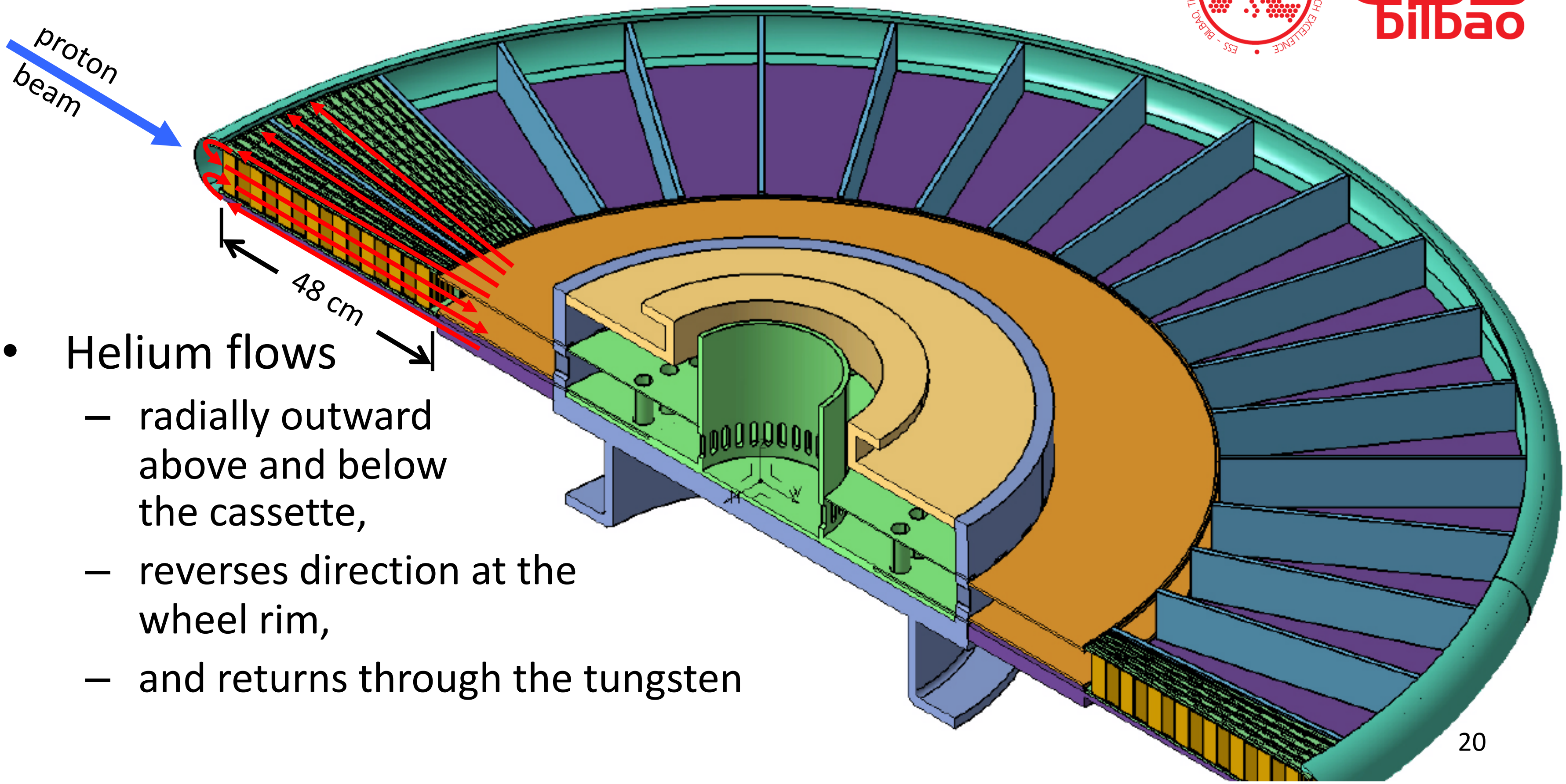
Rotating targets for spallation sources are not a new concept

- Main advantages:
  - Can accommodate high beam powers
  - If properly designed, decay heat can be removed passively
  - Long life
- Main drawbacks:
  - Large, heavy, expensive target
  - Components beneath the target wheel are difficult to extract

Prototype rotating target from the 1980s-era German SNQ project (Forschungszentrum Jülich)

Each 10° sector is filled loaded with a tungsten-filled cassette

- Tungsten depth in the proton beam direction is 45 cm
- The range of a 2-GeV proton in tungsten is 74 cm



- Helium flows
  - radially outward above and below the cassette,
  - reverses direction at the wheel rim,
  - and returns through the tungsten

ESS will be the first high-power spallation target cooled by helium

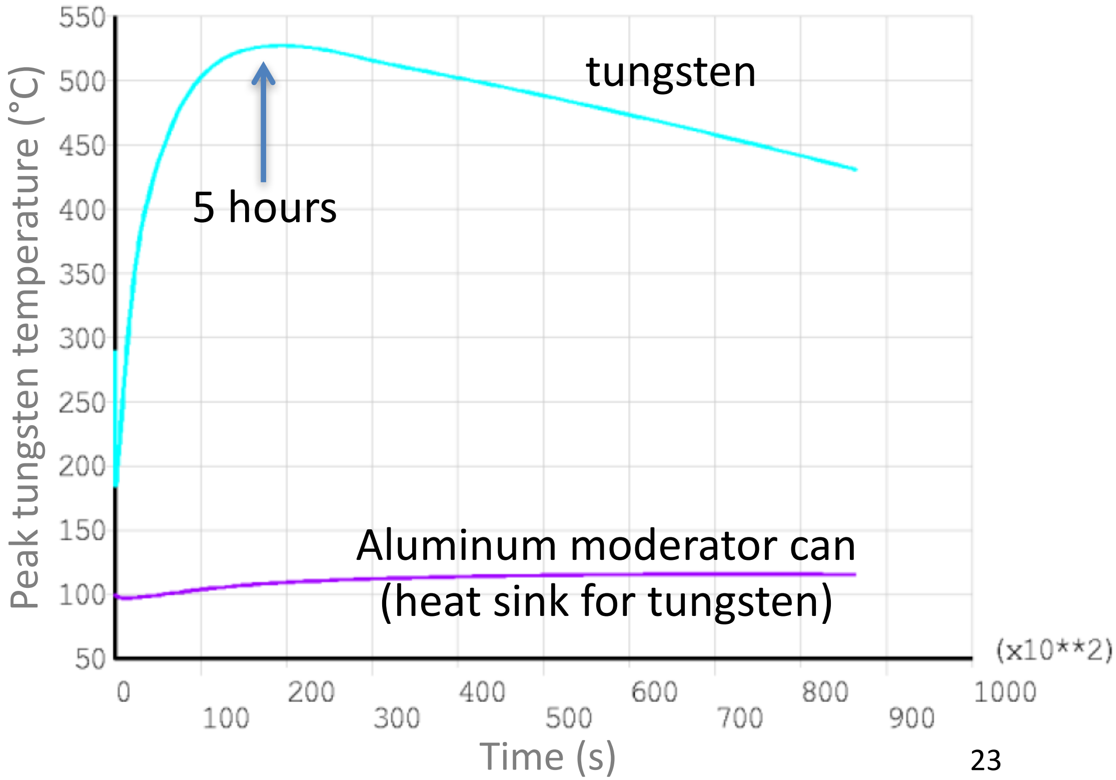
- 3 MW cooling capacity
- 30 kg helium inventory
- 3 kg/s flow rate
- 10 bar absolute pressure, 1.5 bar pressure drop
- 40°C inlet temperature, 240°C exit temperature
- Purification system removes contaminants
  - Full-flow filtration to 5 µm
  - 0.1% purification stream filtered to 0.5 µm
  - Getters in the purification stream remove hydrogen, halogens, and other trace elements
- Oil-free turbo compressors appear to be the best option for the helium blowers

The biggest hazard to the public is the radionuclide inventory in the tungsten target

- If this inventory were released, the dose to the most exposed members of the public would exceed permissible limits
- Three energy sources can disperse this inventory:
  - Abnormal heating by the proton beam
    → *Addressed by a highly reliable Target Safety System*
  - Nearly 40 kW of decay heat in the target wheel
    → *Designed for completely passive decay heat removal*
  - Large inventory of liquid hydrogen next to the target
    → *Deflagration or detonation does not heat the target*

Loss of Coolant Accident (LOCA) analysis shows the tungsten remains <700°C

- Radiative heat transfer only from the wheel to the surrounding structures (assumes the wheel is in vacuum)
  → *no active cooling, no convection or conduction*
- Initial decay heat in the tungsten is 40 kW
- Target Safety System shuts off beam
- SS emissivity = 0.6
  Al emissivity = 0.2
- Peak tungsten temp of 530°C is reached 5 hours after loss of coolant



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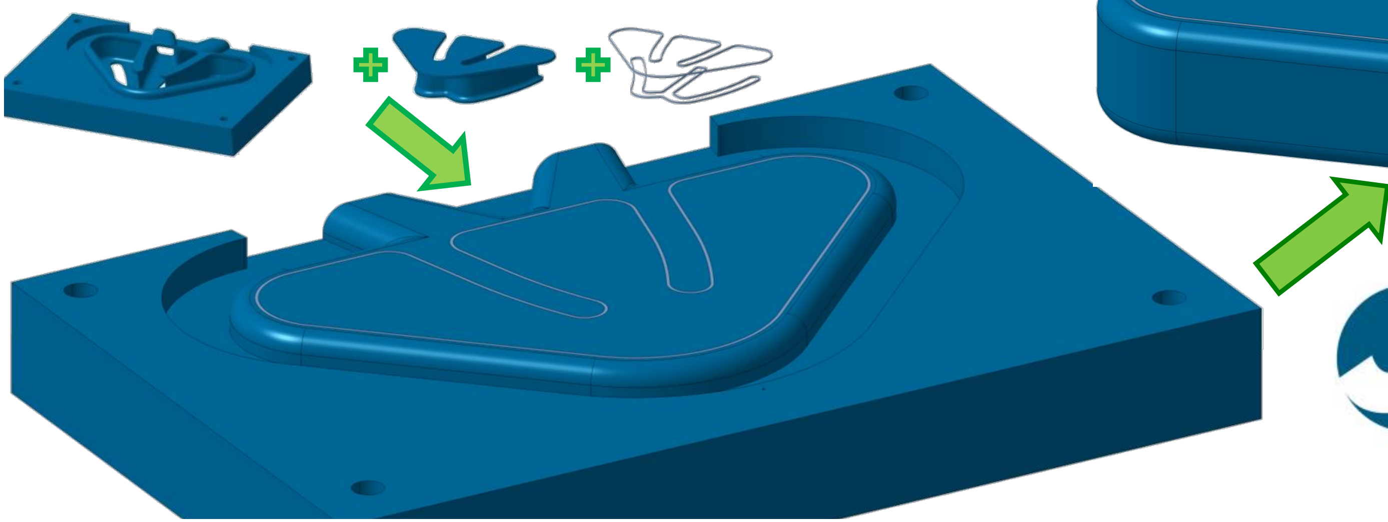
Cold moderator design puts welds in low stress regions

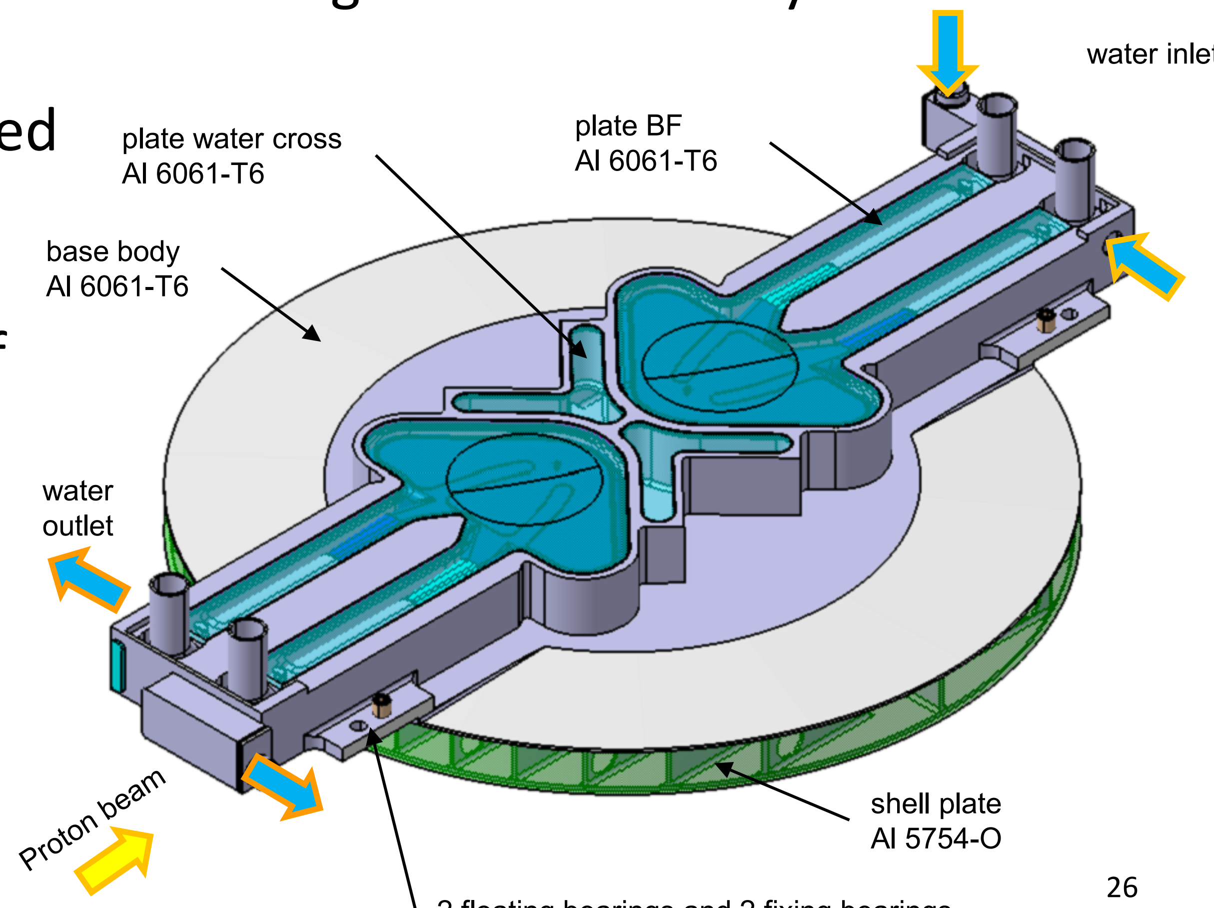
- The inner contour is milled out from solid Al 6061-T6, with a 5-mm backcut to get the welding zone in low-stress regions
- The outer contour is only partially milled to keep a support frame for e-beam welding, minimizing thermal distortions
- After welding, the outer body is cut via wire EDM



JÜLICH
FORSCHUNGSZENTRUM

Thermal moderator manufacturing involves detailed fabrication steps

- Re-stamping and cutting of thermal moderator parts
- First milling and EDM-machining of the base body
- Clean and vacuum packing of machined parts prior to e-beam welding
- e-beam welding of base body with shell plate
- Final milling of the base body



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Two options for the monolith atmosphere are currently being evaluated

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Baseline:
Helium in Monolith Vessel

- Proton beam window installed
- Monolith atmosphere is high purity helium, nominally 1 bar
- Monolith vessel and accelerator beam tube are physically separated by the proton beam window
- Monolith atmosphere system includes equipment for water removal and helium purification

Alternative:
Vacuum in Monolith Vessel

- Proton beam window may not be required
- Monolith vessel operates in either
  - High vacuum, 10^{-4} – 10^{-5} mbar
  - Rough vacuum, 1 – 10 mbar
- Monolith vessel is directly connected to the accelerator beam tube that operates at ultra high vacuum
- Monolith vacuum system will evacuate water and air in-leakage

Option to operate the monolith vessel in vacuum, without a proton beam window

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- Increased facility availability
- Decreased operational costs
- Decreased radioactive waste stream
- Reduced dose to workers (ALARA)
- Passive shutdown of accelerator in case of certain failures
  - Loss of helium (LOCA) or helium flow (LOFA)
  - Loss of wheel rotation
- Improved proton beam quality on target (sharper beam edge)
- Reduced activation of in-monolith components near the beam path

Drawbacks, weaknesses and risks with high vacuum operation option

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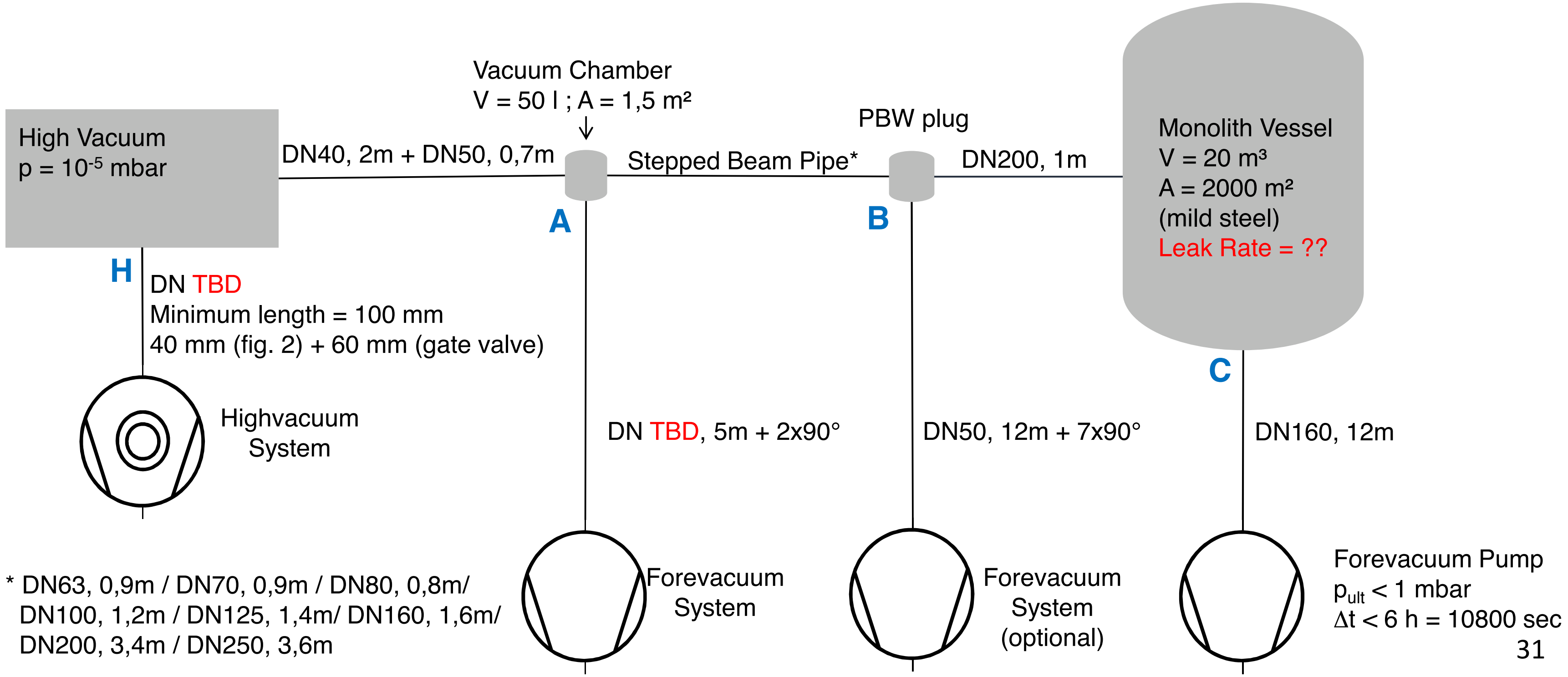
- Requires design and manufacture to high vacuum standards and practices
  - Cleanliness
  - Allowable materials
  - Surface treatments
  - Manufacturing (e.g., machining, weld procedures and inspection)
  - Handling and transport
- Questionable ability to deal with fluid leaks that may occur during facility lifetime due to, e.g.:
  - Thermal fatigue
  - Corrosion
  - Mechanical deformation
  - Handling mishaps, like drop of equipment or spill of liquids

Rough vacuum option requires a differential pumping scheme

Concerns:

- Gas load into the accelerator beam line may be too large for a reasonably sized vacuum system
- Potentially corrosive atmosphere in the monolith



* DN63, 0,9m / DN70, 0,9m / DN80, 0,8m/ DN100, 1,2m / DN125, 1,4m/ DN160, 1,6m/ DN200, 3,4m / DN250, 3,6m

Concluding Remarks

- ESS civil construction is well under way
- Machine installation is just starting
- ESS-Bilbao has designed a rotating target, with prototype fabrication of critical components
- FZ Jülich has developed a robust moderator-reflector design with demonstrated manufacturability
- Options for operating the monolith atmosphere under vacuum are currently under evaluation

ESS-related work presented at IWSMT-13

- Monday
  - Pulsed heavy ion irradiation of tungsten **Jemila Habainy**
- Tuesday
  - Formation of oxide layers on tungsten in mildly oxidizing gas **Jemila Habainy**
  - Fatigue properties of tungsten from different processing routes **Jemila Habainy**
  - Luminescent materials development for beam-on-target imaging **Tom Shea**
  - Design and fabrication of a passive irradiation module **Yongjoong Lee**
- Wednesday
  - The ESS helium cooled rotating target **Fernando Sordo**
  - Manufacturing of the ESS cold moderator **Yannick Beßler**
  - Thermomechanical analysis of the ESS spallation material **Fernando Sordo**
- Friday
  - Material selection of the beam profile monitoring devices **Yongjoong Lee**

Target Station and Instrument Hall construction sequence