CHALLENGES for the BEAM INSTRUMENTATION of the ESS TARGET and the role of the HiRadMat facility

Elena Donegani, Monika Hartl, Yong Joong Lee,
Thomas Shea, Cyrille Thomas, Mattias Wilborgsson
(European Spallation Source)

Erik Adli, Greyson Christoforo, Håvard Gjersdal (Oslo University)
Mikael Jensen (DTU), Shrikant Joshi (H.V.)

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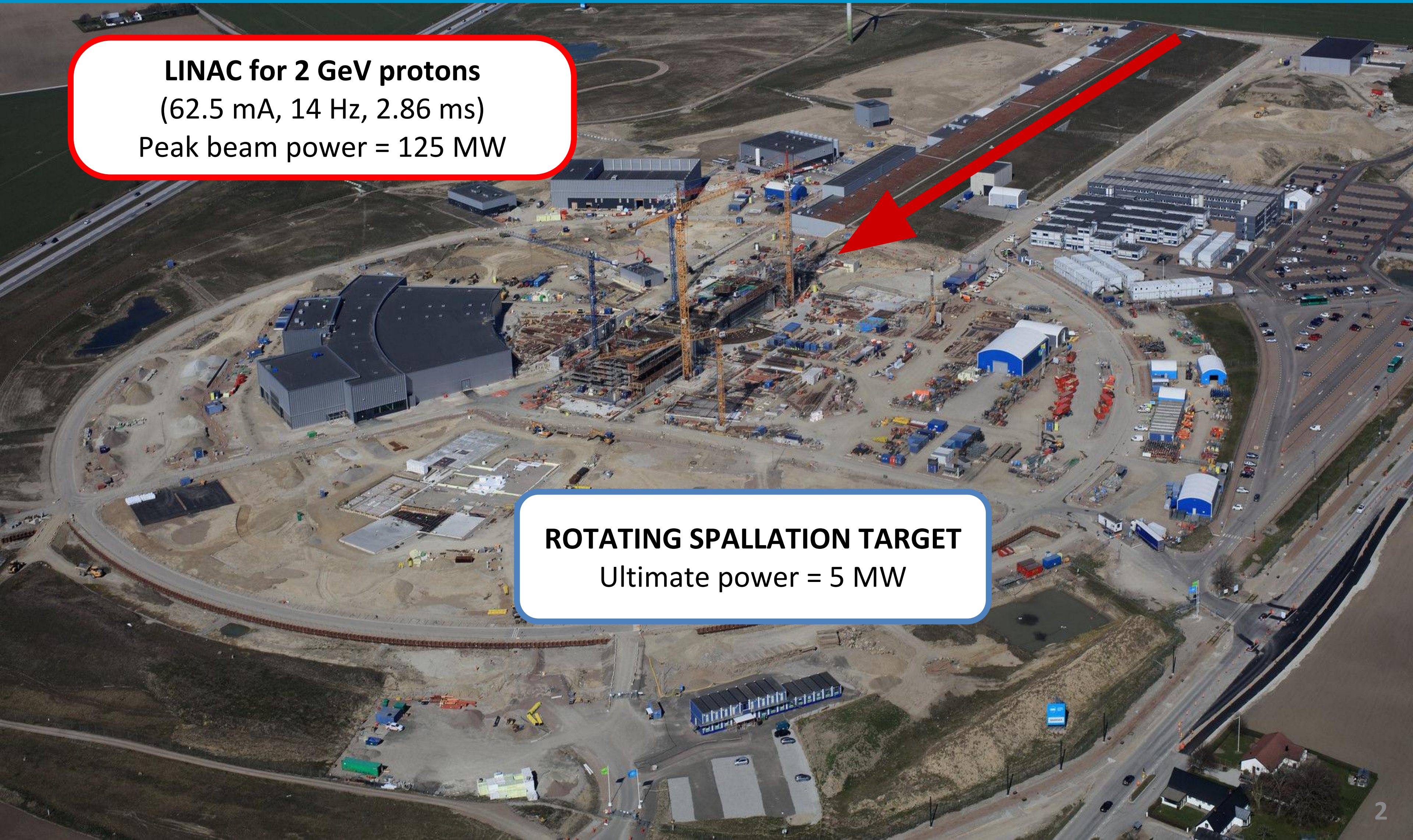
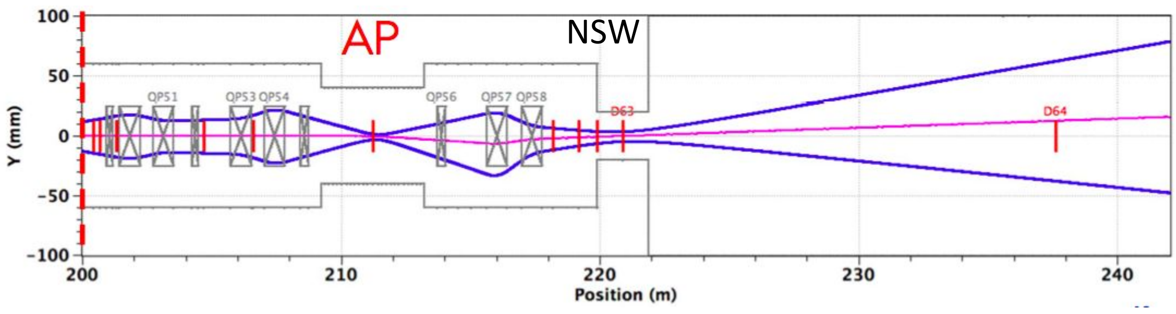
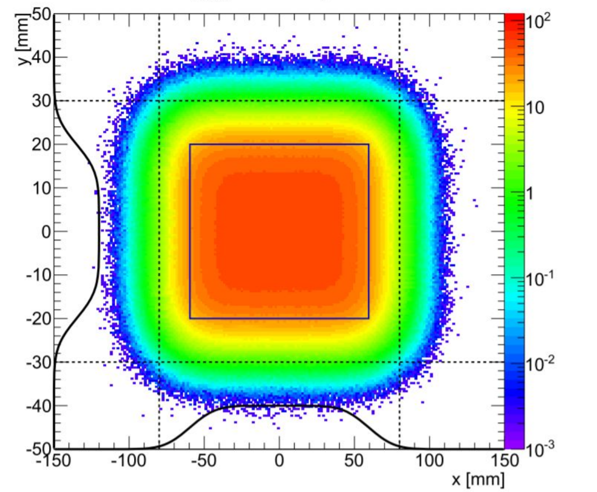


ESS A2T



Nominal time-averaged peak current density

$\langle J \rangle_{max} = 52.8\ \mu A/cm^2$



A set of quadrupoles + raster scanning (10 mm/µs)

→ **REDUCED POWER DENSITY:**

from 10 mA/cm^2 to less then 0.1 mA/cm^2

→ **REDUCED HEAT DEPOSITION AND RADIATION DAMAGE:**

0.5 year for the PWB and 5 years for the target

MONITOR:

- beam halo, position, current and pulse's time of arrival

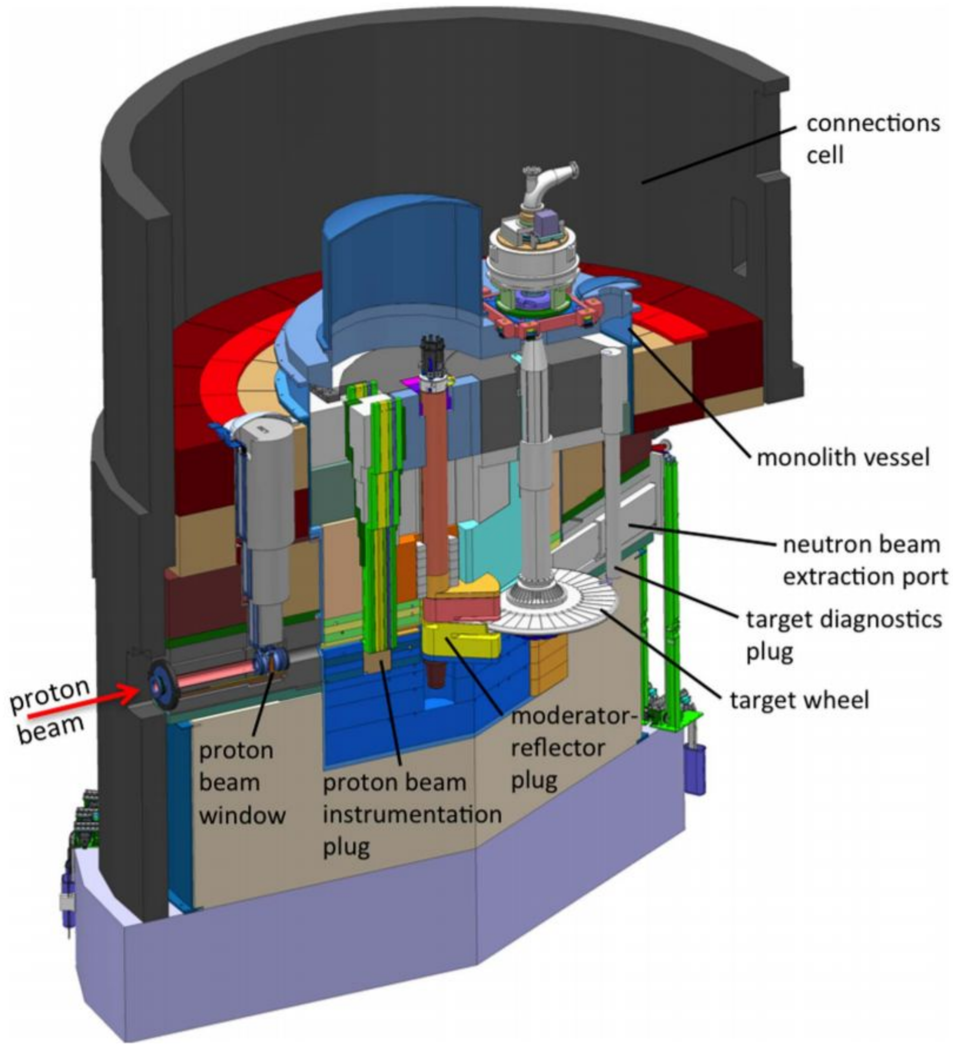
→ synchronize the beam with the rotating target

- beam density distribution at PBW and target

→ detect errant beam conditions or target malfunctioning

Errant beam detection	60 ms
Damaging pulse detection	10 µs
Density accuracy	20%
H centroid accuracy	3 mm
V centroid accuracy	2 mm
Beamlet centroid precision	2 mm

ESS target monolith



ROTATING TUNGSTEN TARGET

- Diameter = 2.5 m, with 7000 tungsten bricks
- Helium-filled for cooling

→ heat deposited from 5 MW proton beam

IN ONE YEAR:

- 7 million thermal cycles of 100 °C per year

(p) On the PBW: max 0.7 dpa & 140 appm of He

(n) Elsewhere: max 1.2 dpa & 1.6 appm of He

Commissioning and operation of linac and target:

- beam size, position (IMG)
- beam current density distribution (IMG, GRID)
- beam outside defined aperture (APTM)

#1 IMAGING

Based on optical components in the PBIP + luminescent coating of PBW and target wheel

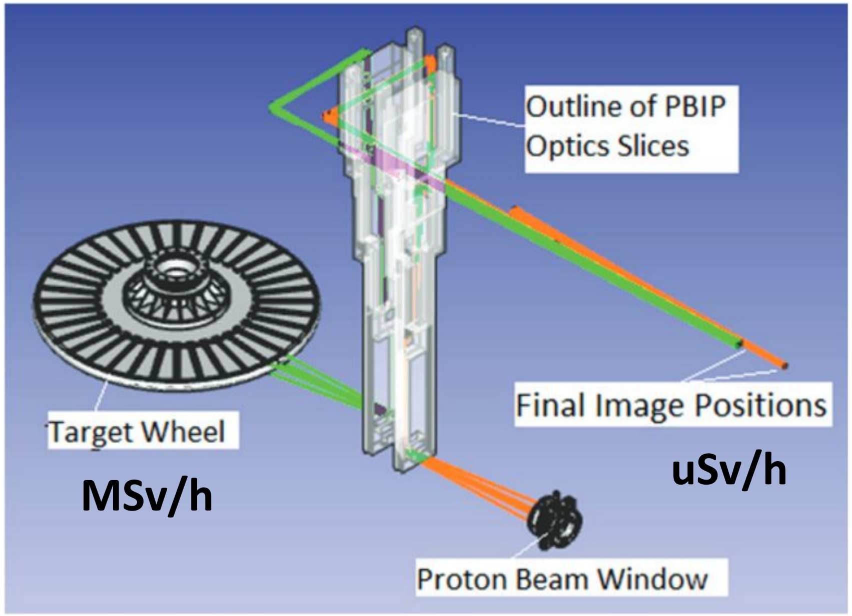
- Online 2D profile(s) and density distribution(s)

CHALLENGES:

1) Spectral filtering to isolate coating emissions from gas emission (He gas luminescence)

2) Failure of raster scanning
- high current densities and surface temperature
- inhibit beam before next pulse arrival

3) Detect both static and rastered beam
→ need for a large numerical aperture
→ need for transporting images 15 meters away



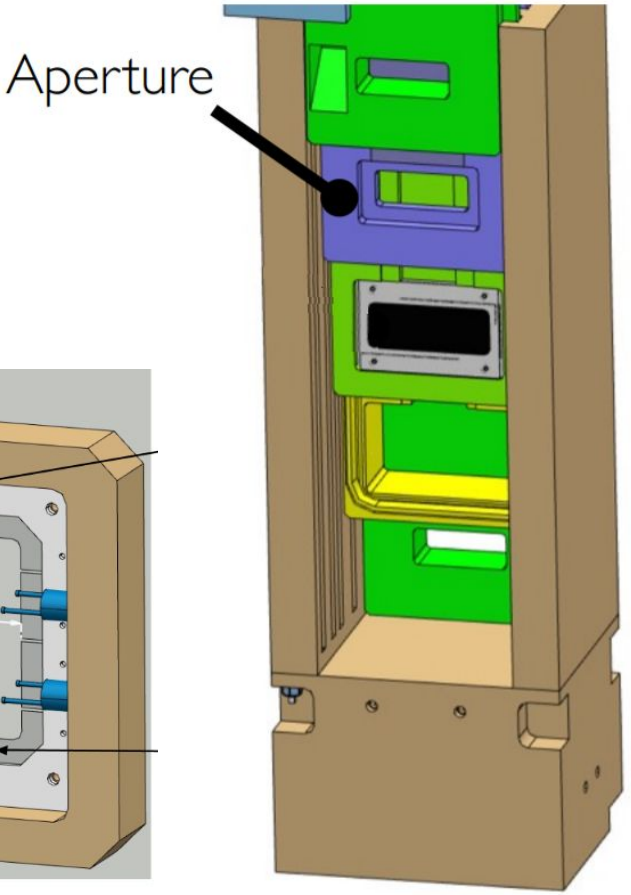
Proton Beam Instrumentation Plug (PBIP):
- to transport images to the top/out of the monolith
- to maintain shielding integrity
- to allow insertion and remote handling of BD

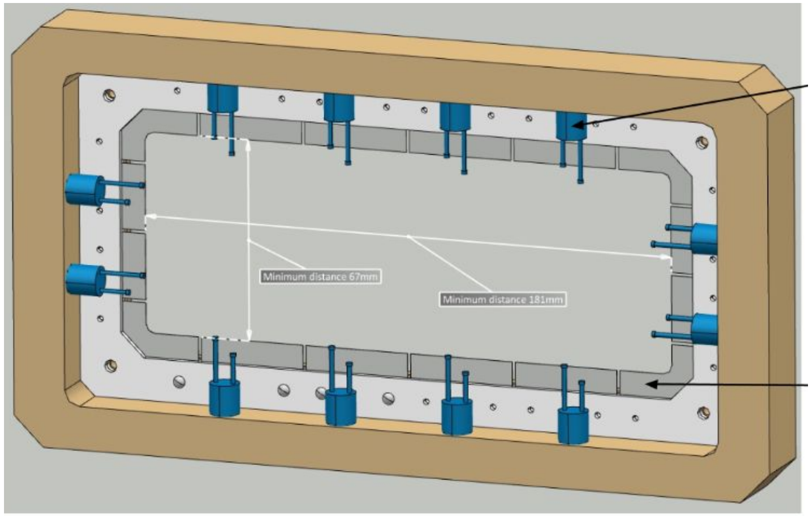
#2 APERTURE MONITOR

Based on thermocouple assemblies and secondary emission blades

APTM in the PBIP (i.e. exposed to mixed irradiation fields):

- Charge deposition via SEE and δ-ray production
- Nickel is the the main structural material (PSI)
- To center the beam in the target monolith
- Working up to the full production beam
- To detect errant beams → interlock





#3 GRID MONITOR

Based on multi-wire grids to measure beam current density (1D) in H/V

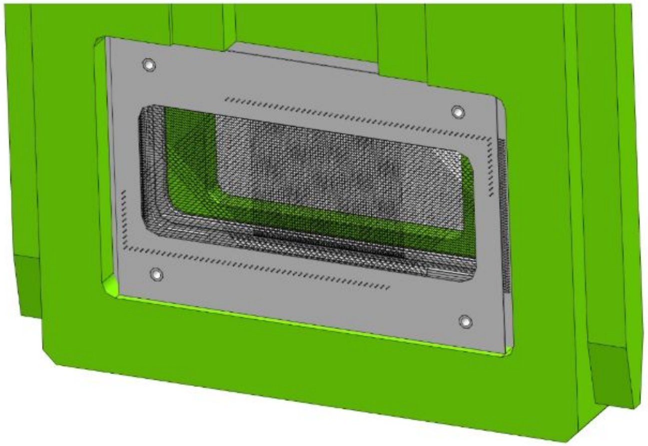
100E-6 m tungsten wires with a spacing of about 2 mm

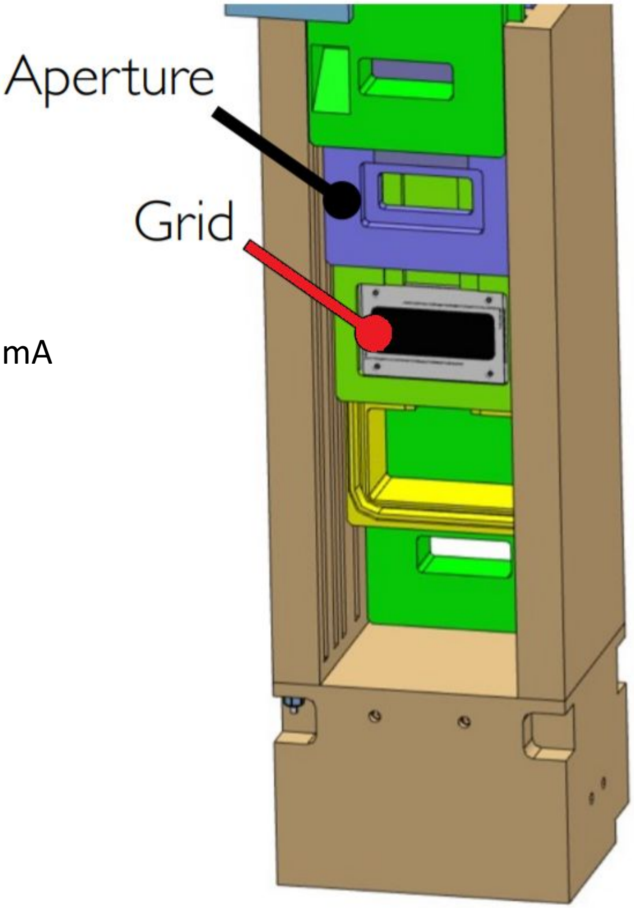
Operating in ionization mode

T < 900 K, avoiding thermionic emission

Inside the PBIP and upstream the PBW:

- Permit and monitor neutron production, i.e. operative from 6 mA to 62.5 mA
- To detection abnormal beam position and current density → interlock

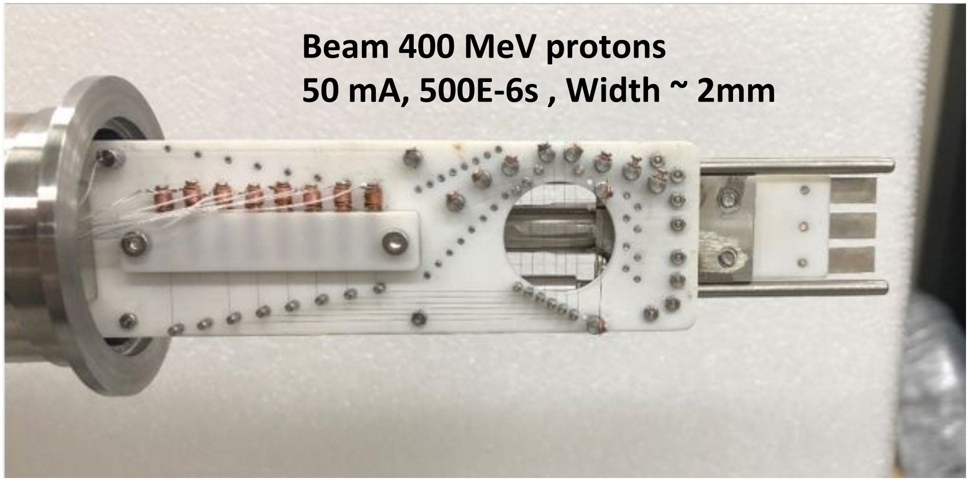


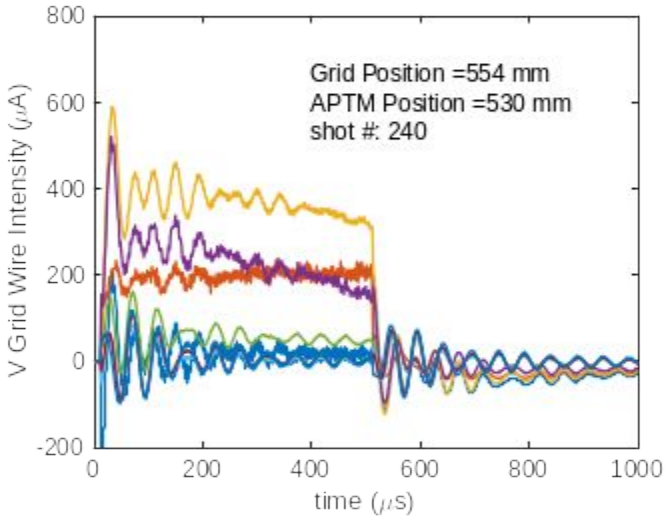


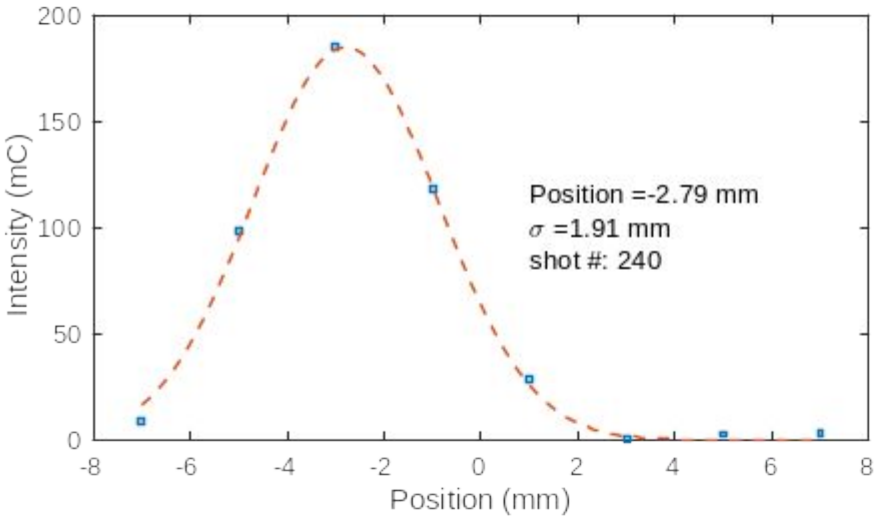
APTM&GRID prototype: test

Prototype tested at J-PARC, based on:
2 Thermocouples + 3 Ni-blades
16 W wires + 1 SiC wire

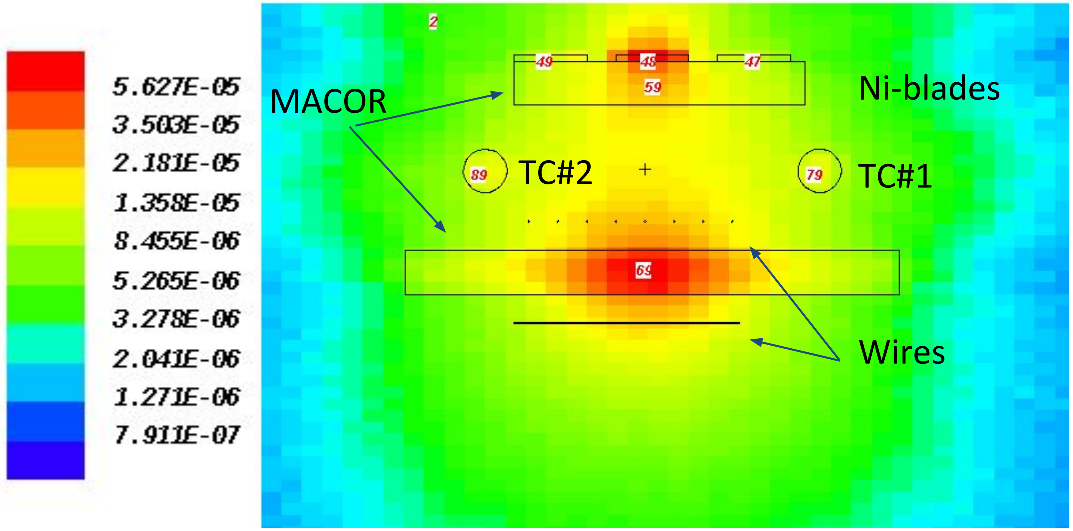
Test of:
- Motion control
- W and SiC wires signal
- Thermocouple and Ni-blades signals
- Cross-talk between wires
- Cross-talk between GRID & APTM

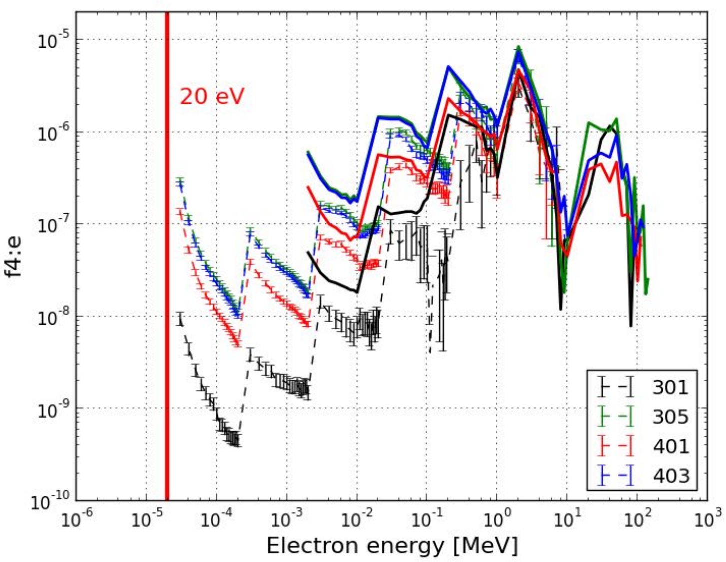






APTM&GRID prototype: simulations

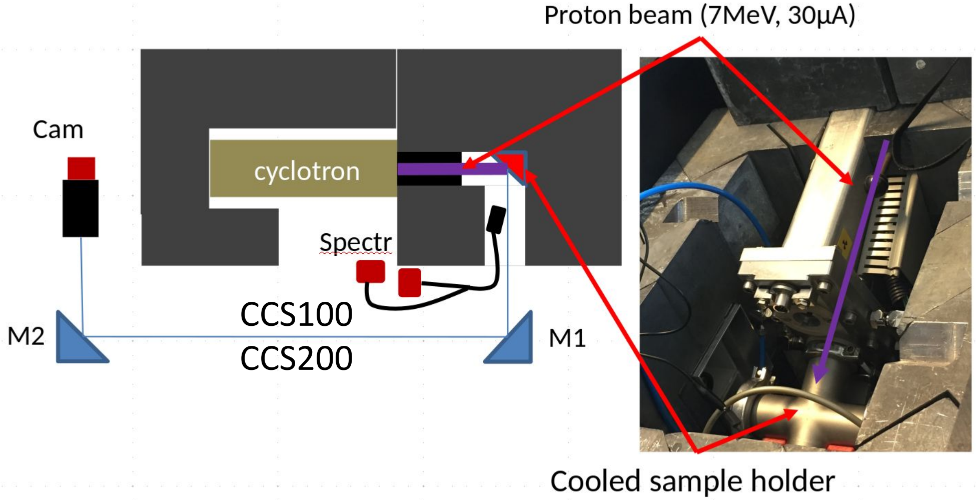




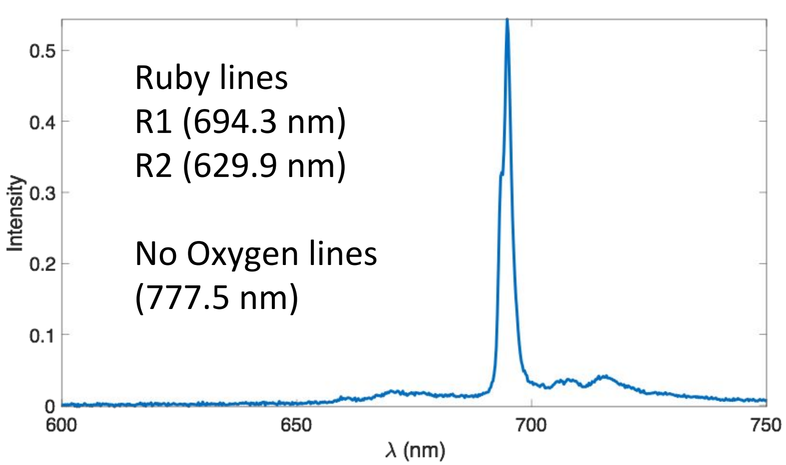
- Electron flux (#/cm^2), 2D map (YZ, 1x100x100 voxels over a 4x1.8x0.2 cm area)
- Electron energies down to 20 eV, but mainly MeV-electrons
- Need to discriminate charge deposition from 'knock-on' δ-electrons and 'true' SEY

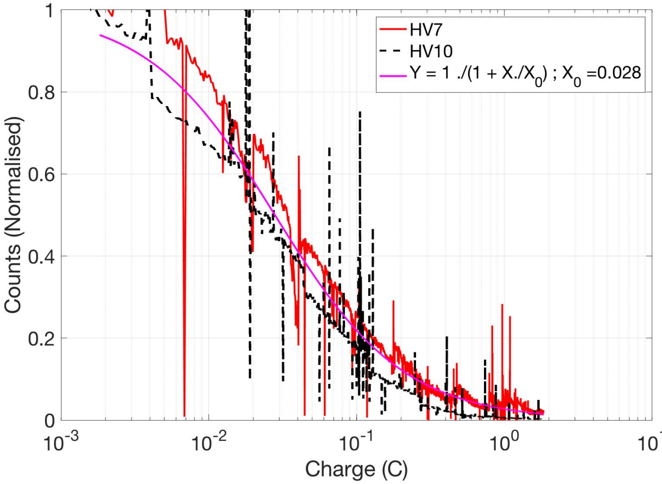
The wires also intersect the secondary particles from the shielding blocks and the PBW
N.B. 350 keV electrons have a stopping range of less than 100E-6 m in tungsten

Imaging at DTU



Prototype tested at DTU, based on:
Luminescent material (Chromox)
2 mirrors, 2 spectrographs, 1 camera
Test of:
- sample cooling
- sample activation
- EPICS control software
- instrument sensitivity
- sample/signal degradation





HiRadMat for ESS: the WISHLIST (1/2)

Optimize MPS and BD to enhance safety and performance of the neutron source

MPS
Online density monitors
Act before the 'next pulse'
Fast electronics

COOLING SYSTEM
360 kJ per pulse (3ms)
Thermal shock
↘ thermal conductivity (n)
↗ thermal expansion

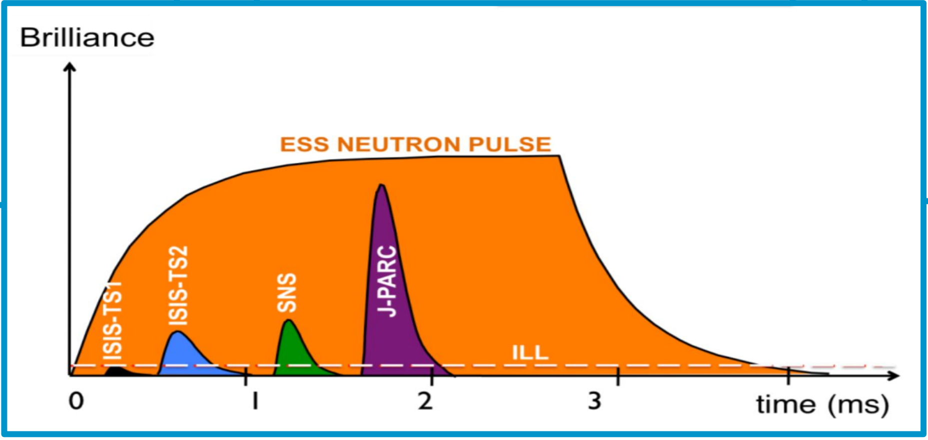
LUMINESCENT MATERIAL(S)
→ Al_2O_3 (Cr 1%)

Photon yield (250 γ/p)
Emission spectrum (wrt 70 ms)
Luminescence lifetime
Radiation hardness (10^{20} p/cm^2)
Vacuum compatibility
He environment
Temperature 200°C

APTM&GRID
SEE energy- and angle yields
exposure to mixed fields

erosion, blisters, cracks
↘ thermal conductivity
↘ thermal expansion coeff.

≠ density
≠ elastic modulus



HiRadMat for ESS: the WISHLIST (2/2)

Optimize BD (interceptive devices) to withstand high damage levels (>10 dpa and several % of He)

1) Little is known about the effects of mixed irradiation fields, on top of H & He effects

- Embrittlement from accumulation of H and He isotopes + accumulation of lattice defects and vacancies
- Temperature effects: localized and cyclic thermal gradients, creating stress waves moving through the materials
- (SHORT) Study the effects of high instantaneous dose rates, gas production and pulsed irradiation
- (LONG) Irradiations with heavy ions whose displacement rates are 10**E5** - 10**E7** orders >> neutrons and protons
- (LONGER) Would it be possible to 'parasitically' irradiate samples at HiRadMat?

2) Database of (compound) materials in spallation targets, especially after fast neutron irradiation

- Measure displacement cross-sections → Input / Cross-check of mechanical and multiphysics simulation codes
- Supporting structures (e.g. SSL sample in a module: 7 dpa max per operational year at 5 MW)
- Max helium production rate in SSL is 110 appm per operational year at 5 MW
- Predict device lifetime, frequency of remote handling and maintenance

References

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Backup

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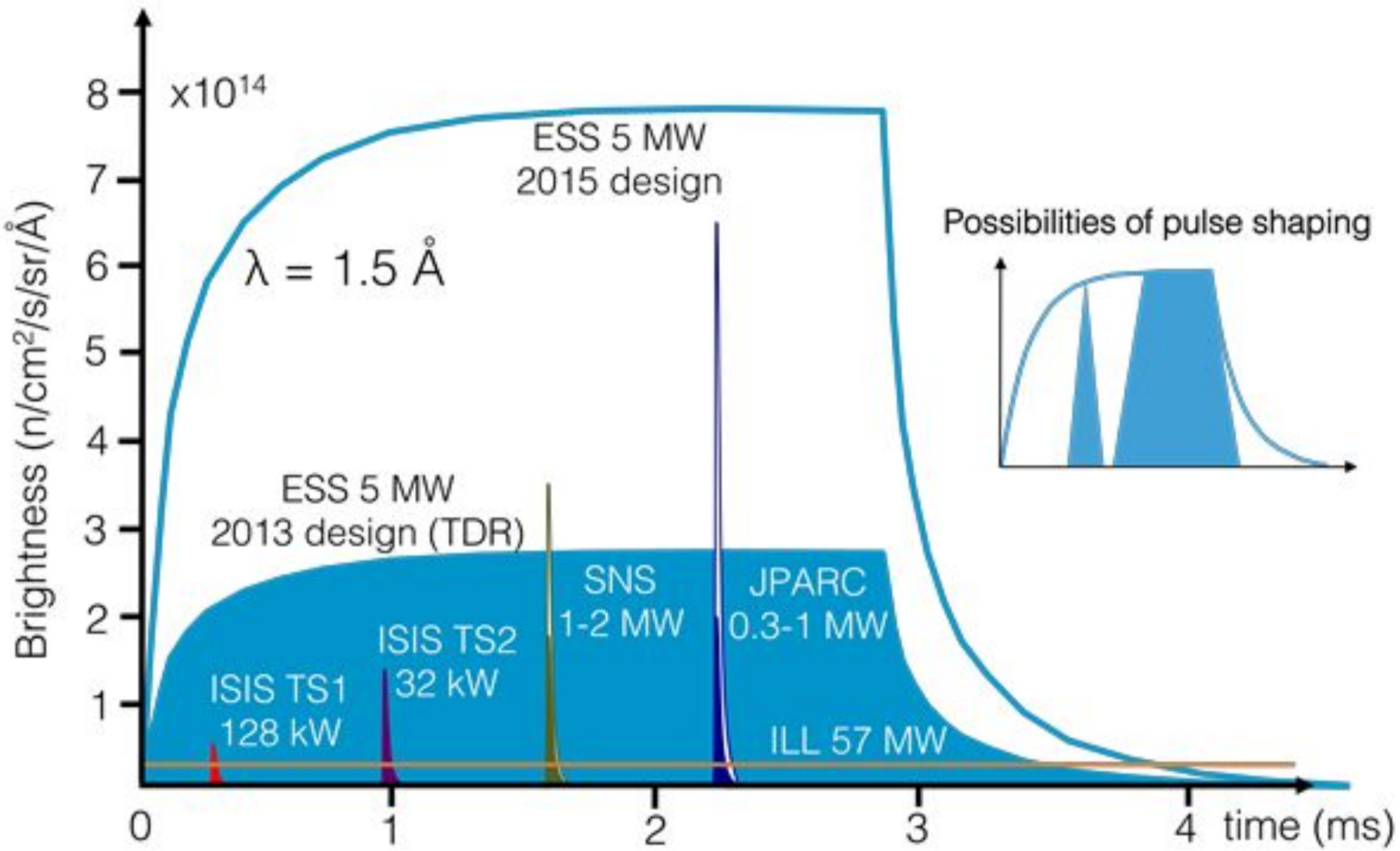
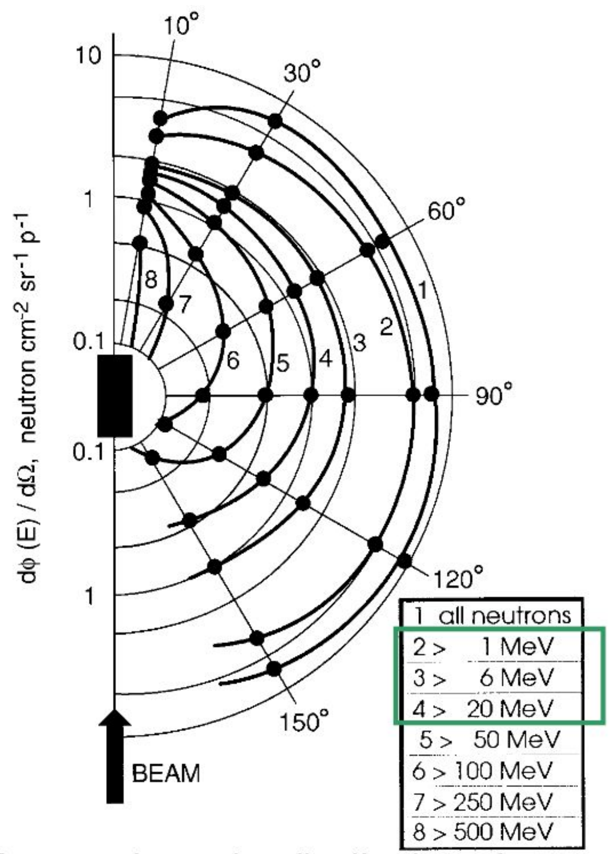
ESS Brightness



2 GeV + LEAD / n angular distribution



Measured angular distribution of neutrons in different energy groups for a 20 cm diameter lead target bombarded by protons of 2 GeV

ESS LINAC

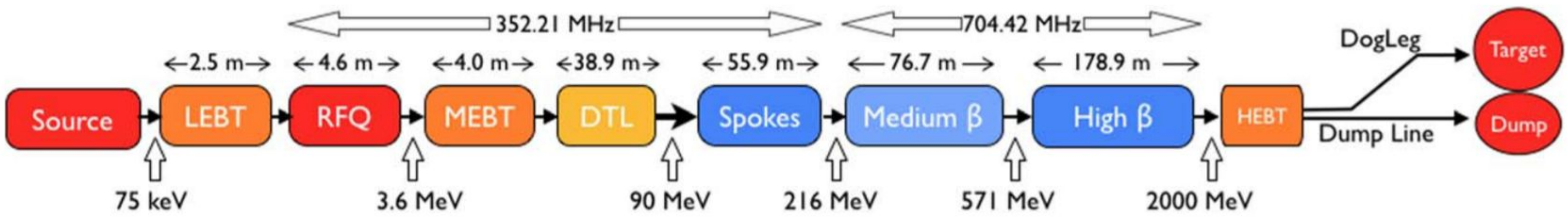
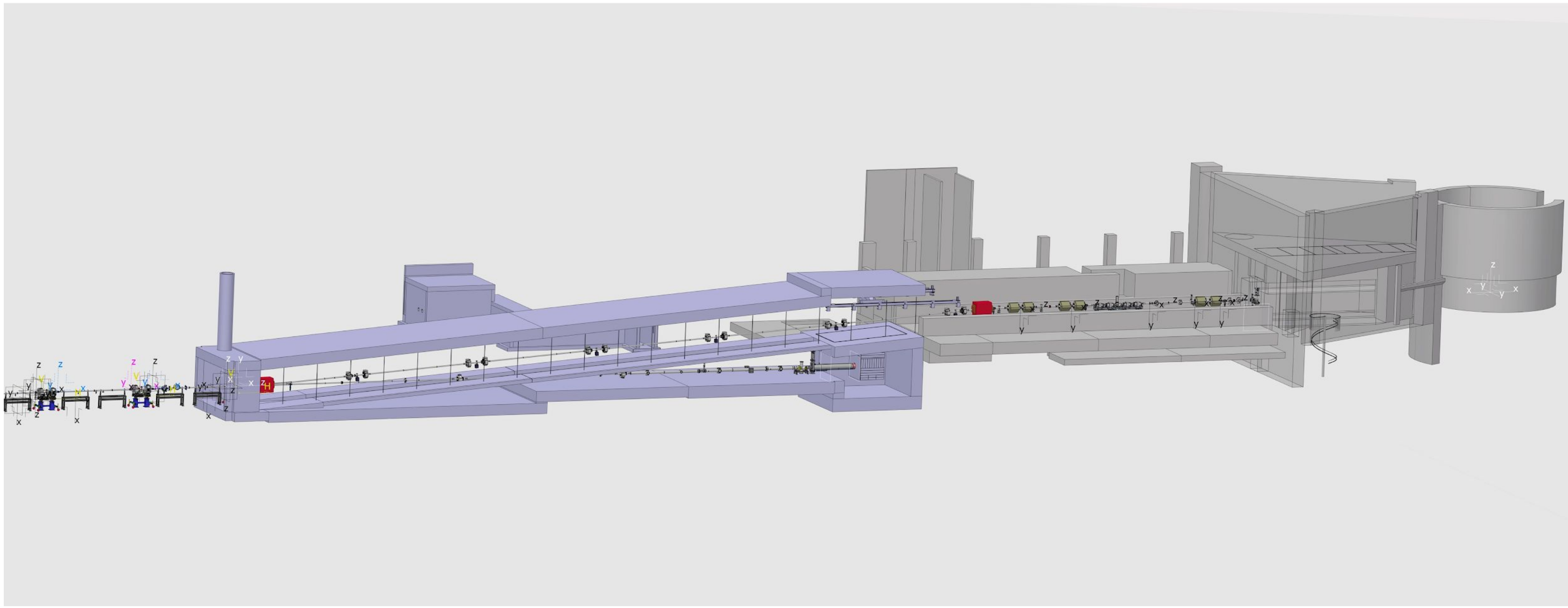
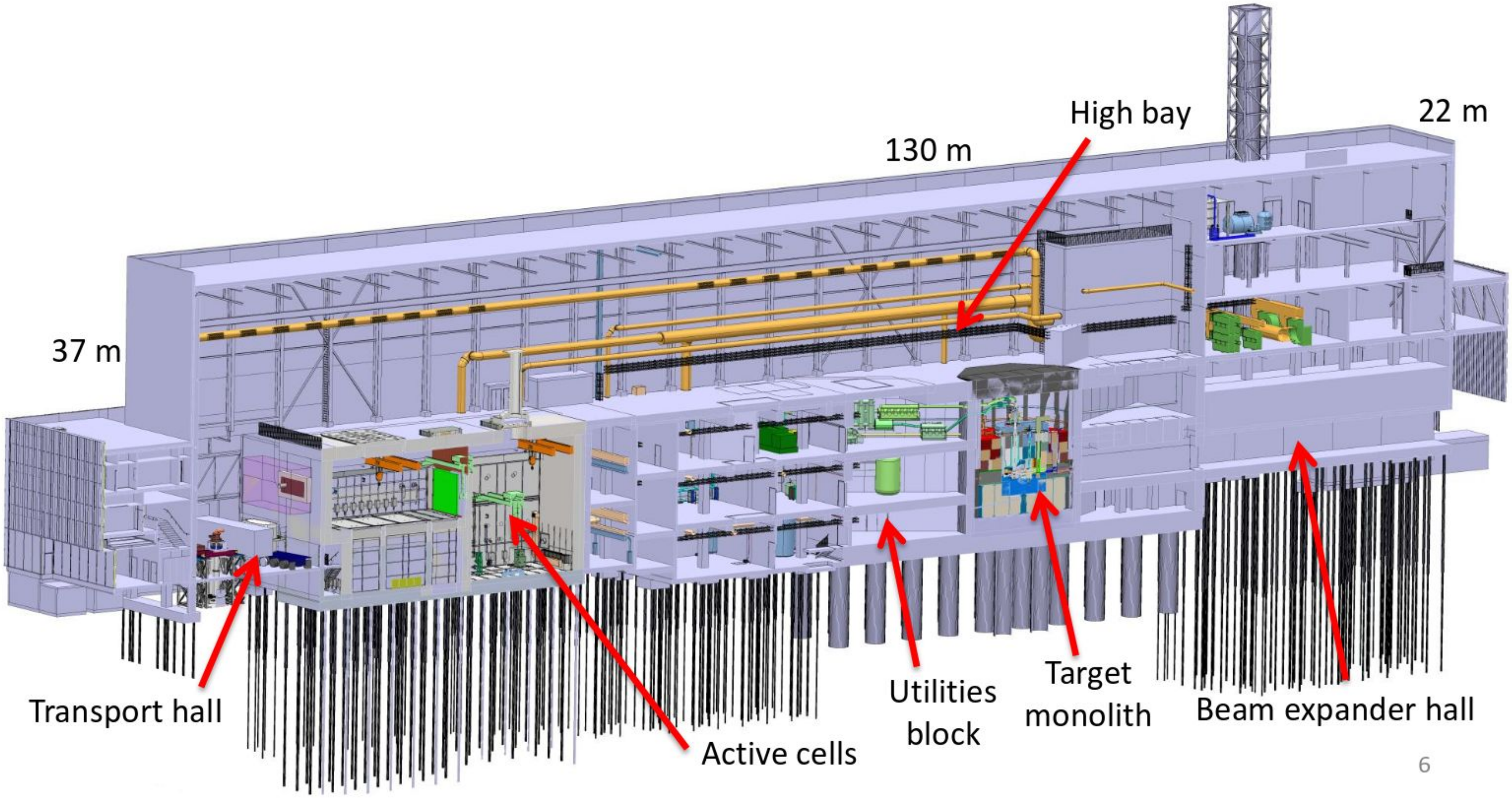


Figure 2. ESS linac layout. Spokes, medium-β and high-β sections are superconducting.



Target and surroundings



APTM&GRID simulations

Air density = 1.17E-6 g/cm³, T=298 K and p=100 Pa. Dimensions in cm