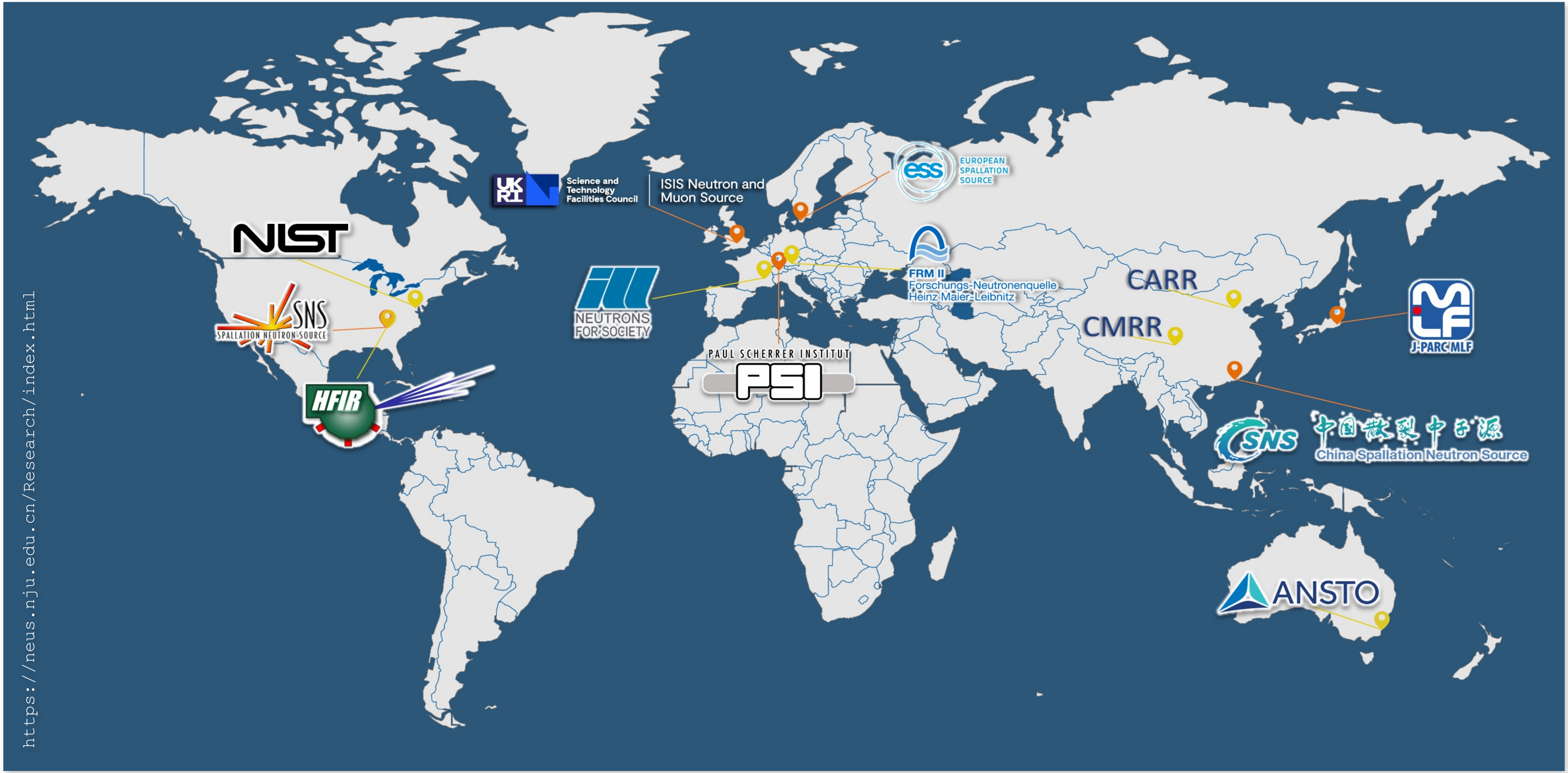
EUROPEAN SPALLATION SOURCE: CURRENT STATUS AND FUTURE UPGRADES

Alan Takibayev
European Spallation Source ERIC
Lund | Sweden

ESS Overview

Selected Neutron Sources Around The World

EUROPEAN SPALLATION SOURCE



ESS Timeline

1999	OECD declaration of intent
2003	First Technical Design Report released
2009	Host selection
2013	Technical Design Update completed
2014	Construction started
2025	Beam-on-Target

ESS Aerial View 2017 October

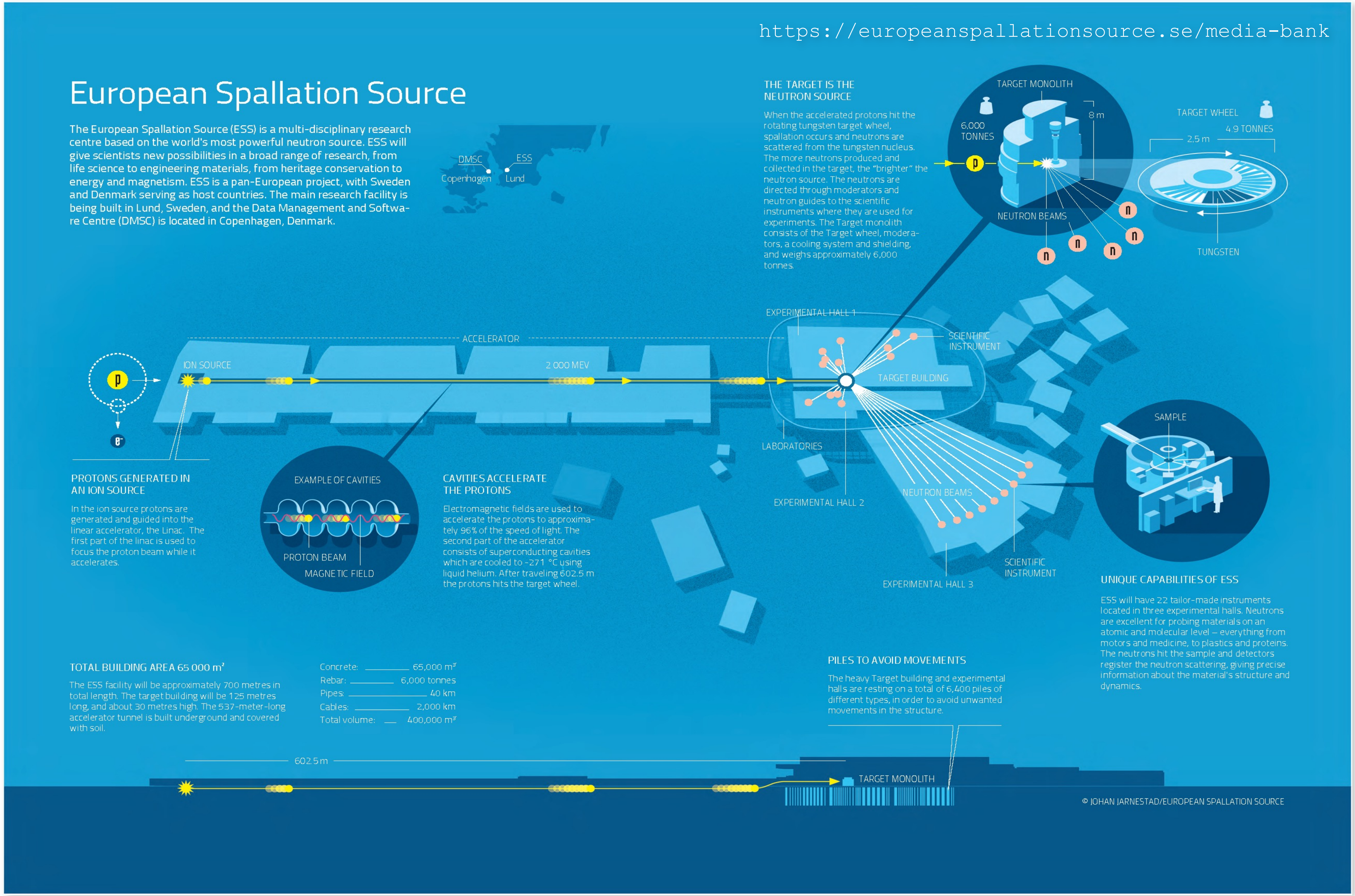
ESS Aerial View 2019 April

ESS Aerial View 2022 February

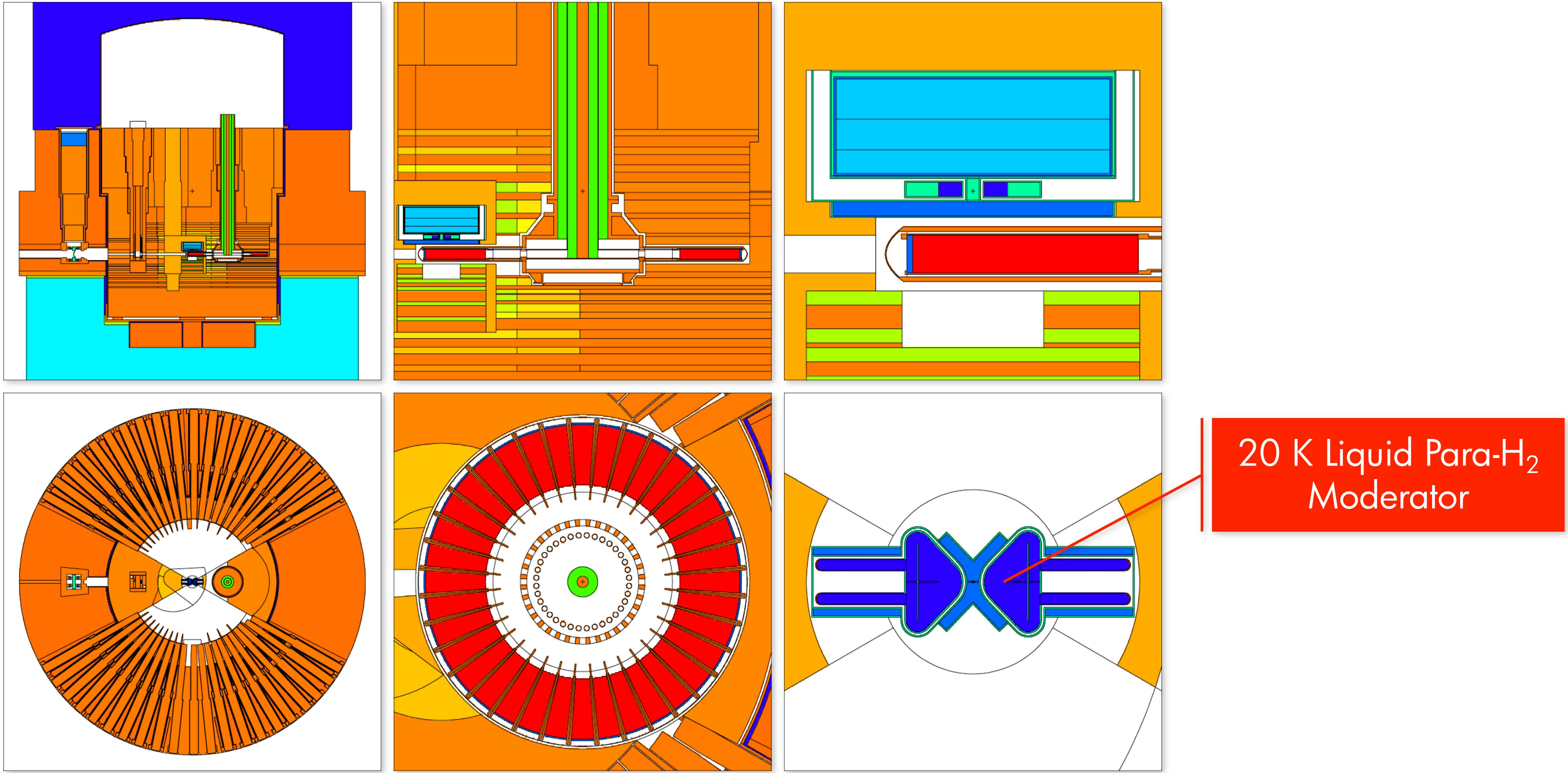
EUROPEAN SPALLATION SOURCE

ESS LAYOUT

EUROPEAN SPALLATION SOURCE

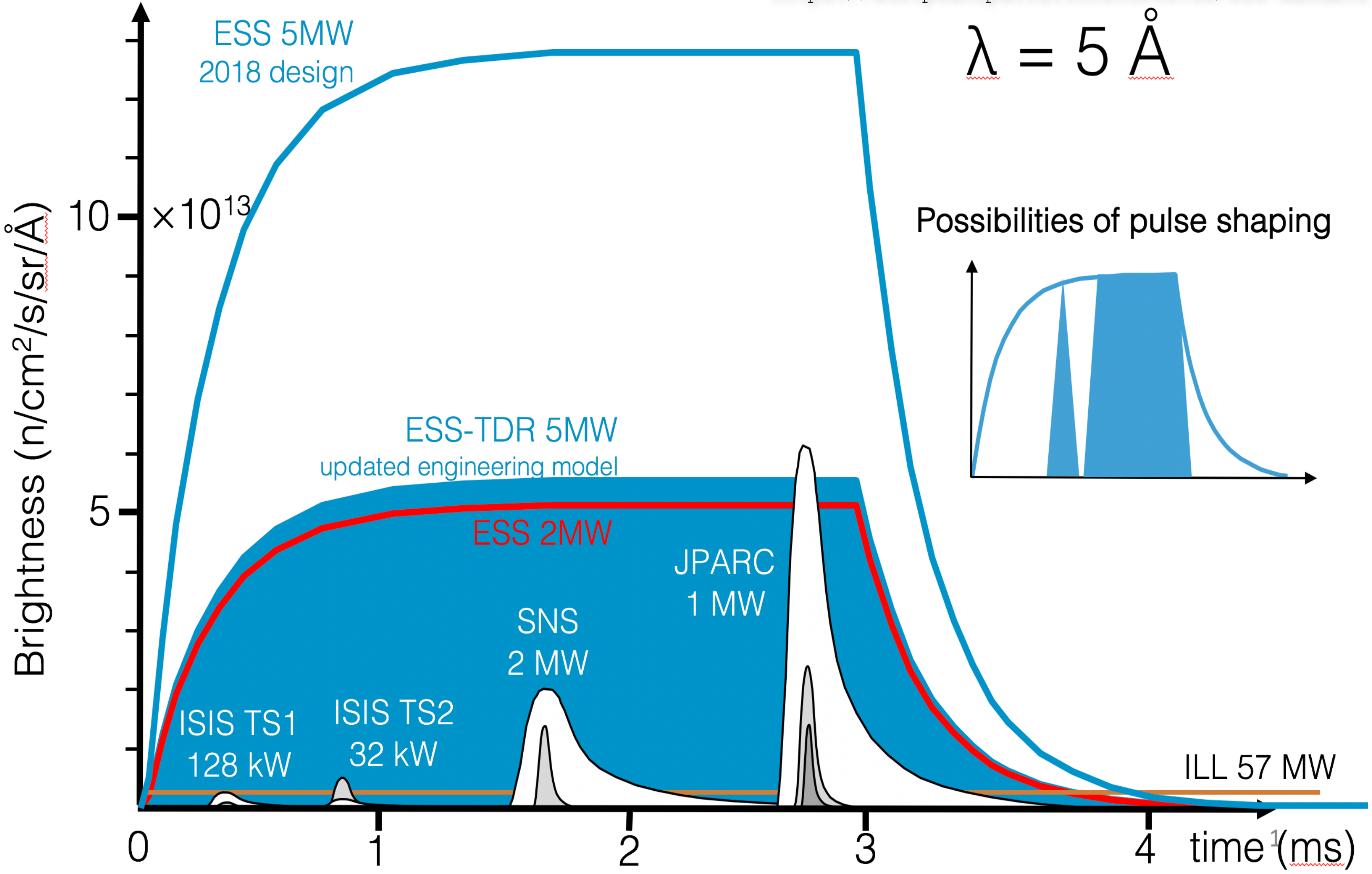


ESS Target Station Monolith



ESS Performance

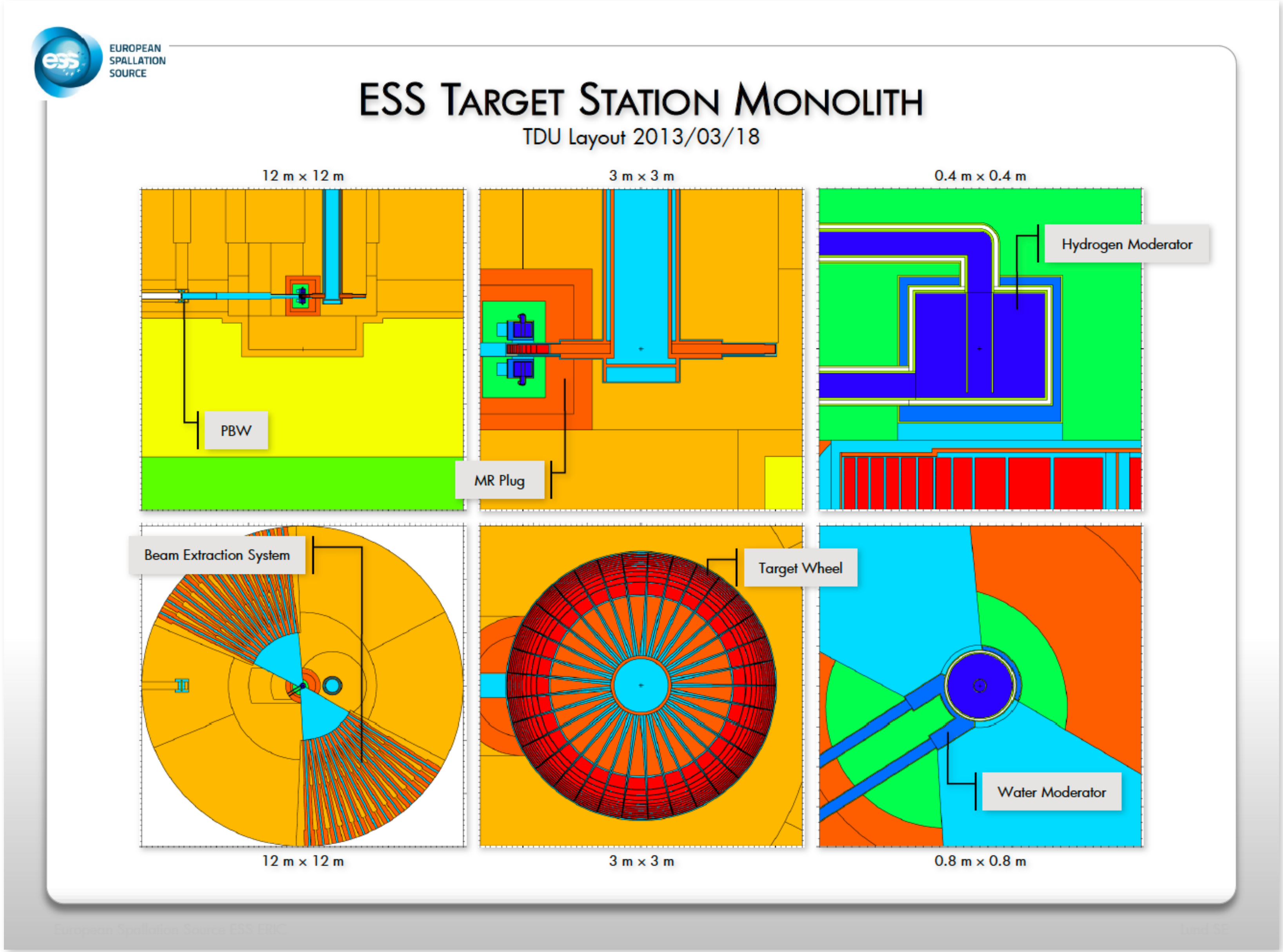
https://europeanspallationsource.se/ess-mandate



The European Spallation Source (ESS), under construction in Lund, Sweden, will be the most powerful neutron source in the world for neutron scattering experiments. The design of the ESS moderator system to produce both cold and thermal neutrons is based on the concept of a high-brightness bi-spectral moderator developed at ESS – the so-called quasi-low-dimensional moderators.

ESS Path to Low-Dimensional Moderators

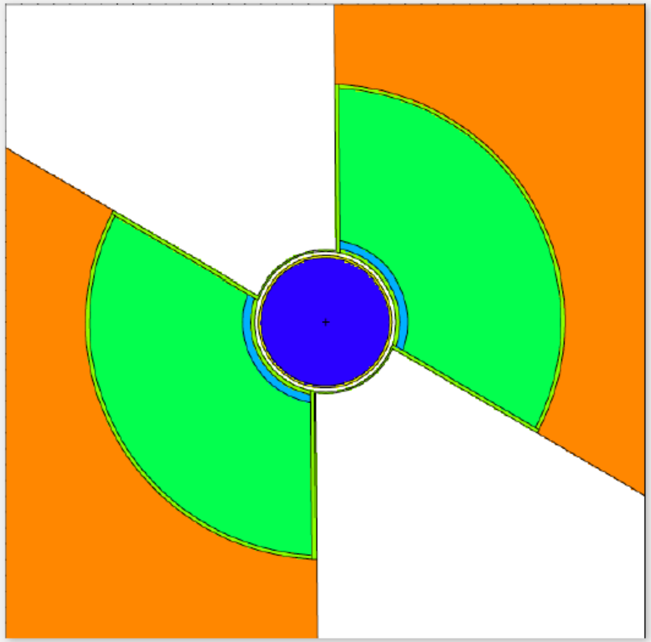
ESS Path to Low-Dimensional Moderators



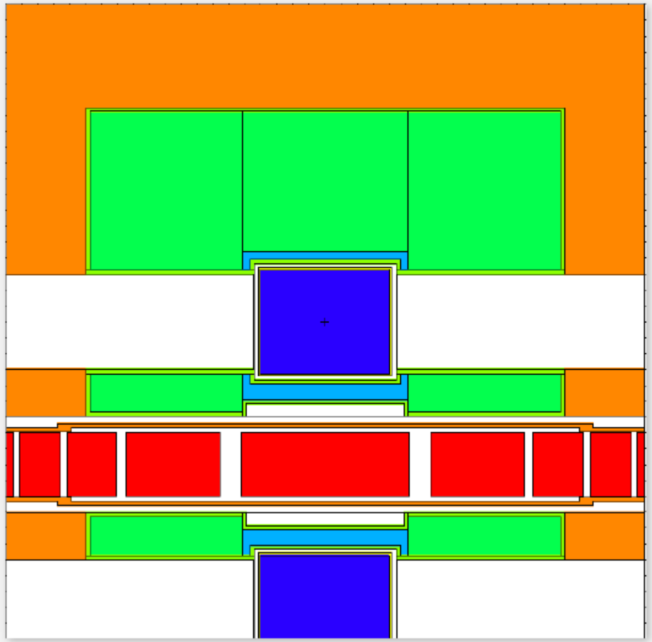
ESS Path to Low-Dimensional Moderators

Generic Volume Moderator

Hydrogen moderator of 13 cm height × 16 cm diameter



View from above
Proton beam comes from the left



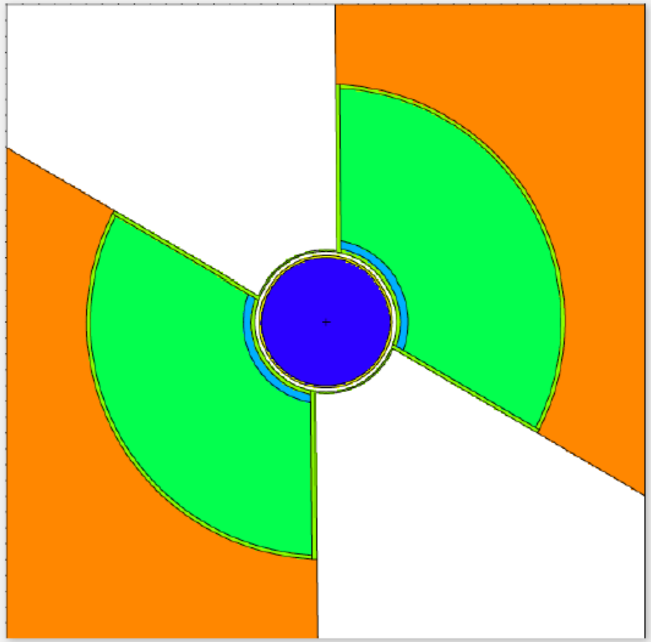
View in proton beam direction
Proton beam comes from behind

0-5 meV Brightness:	1.0

ESS Path to Low-Dimensional Moderators

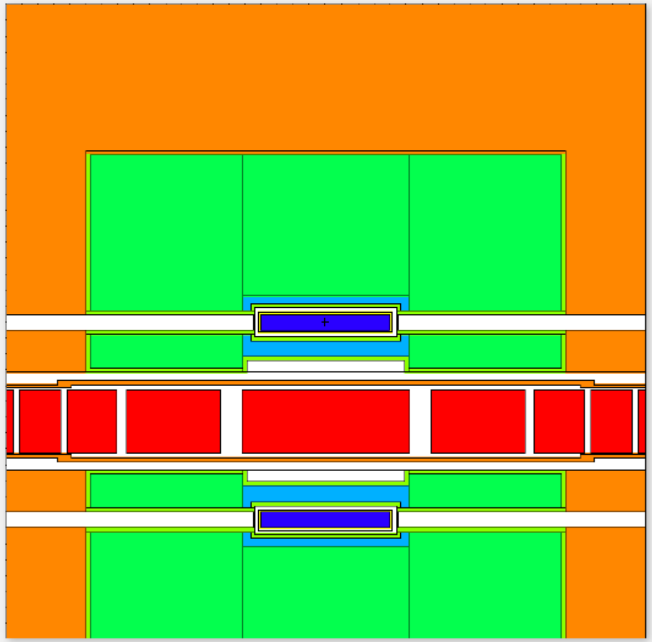
Contracting Moderator Height

Hydrogen moderator of 2 cm height × 16 cm diameter



View from above

Proton beam comes from the left



View in proton beam direction

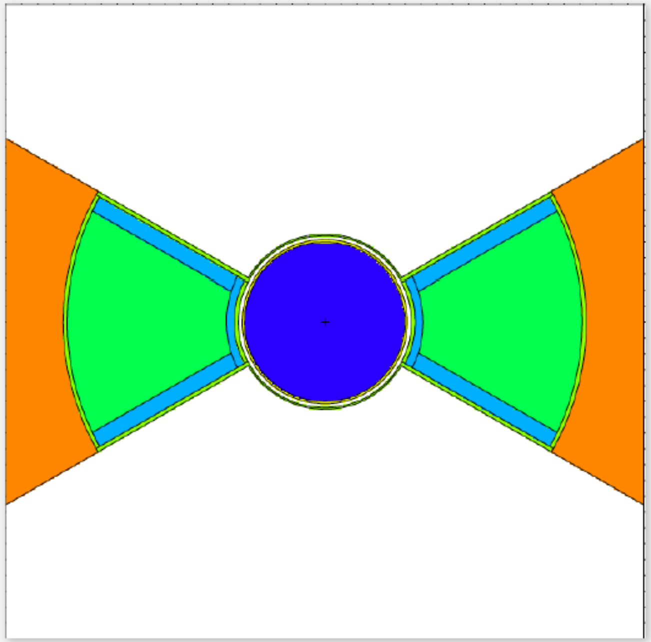
Proton beam comes from behind

0-5 meV Brightness:	**3.0**

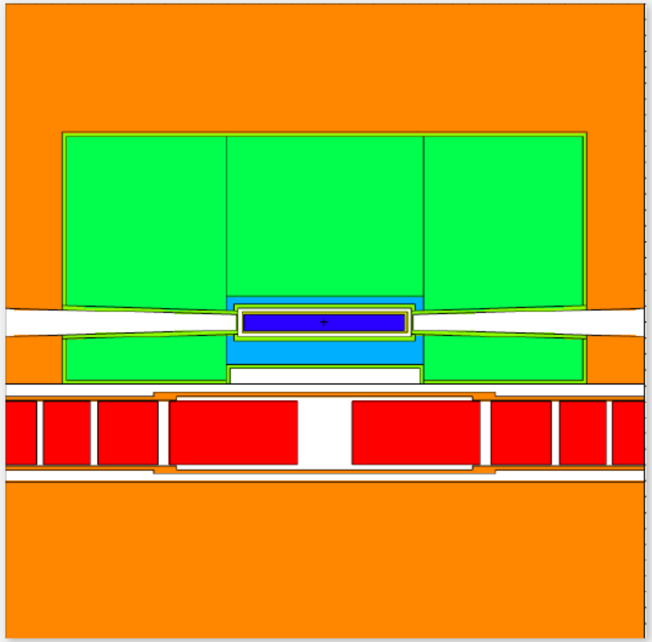
ESS Path to Low-Dimensional Moderators

One Flat Moderator Serving All Beamlines

Hydrogen moderator of 2 cm height × 20 cm diameter



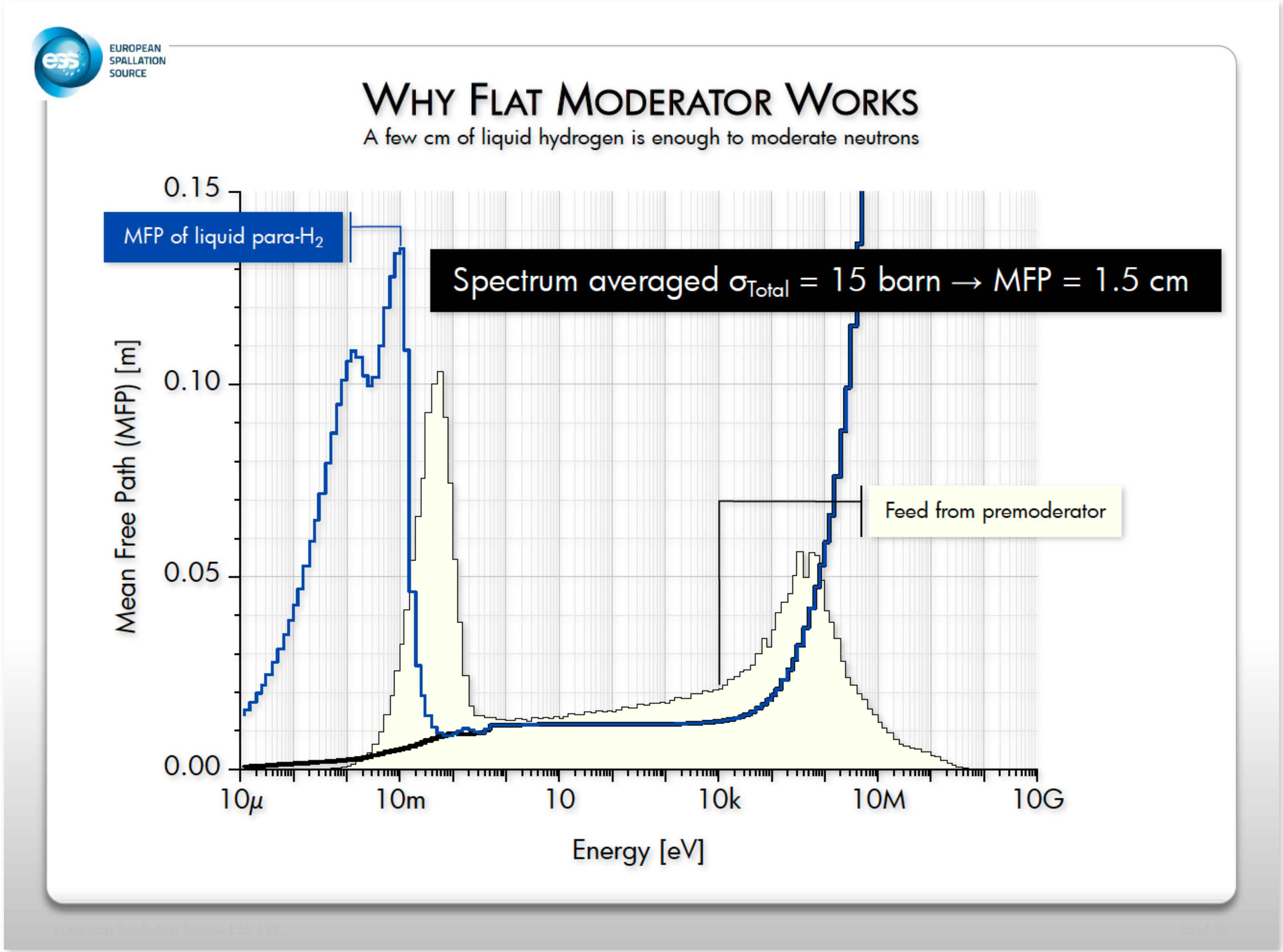
View from above
Proton beam comes from the left



View in proton beam direction
Proton beam comes from behind

0-5 meV Brightness:	**3.3**

ESS Path to Low-Dimensional Moderators



ESS Path to Low-Dimensional Moderators

Physics Summary

Neutrons are effectively moderated in a few cm of liquid hydrogen

Less parasitic absorption due to less amount of hydrogen

Less perturbation due to less amount of reflector removed

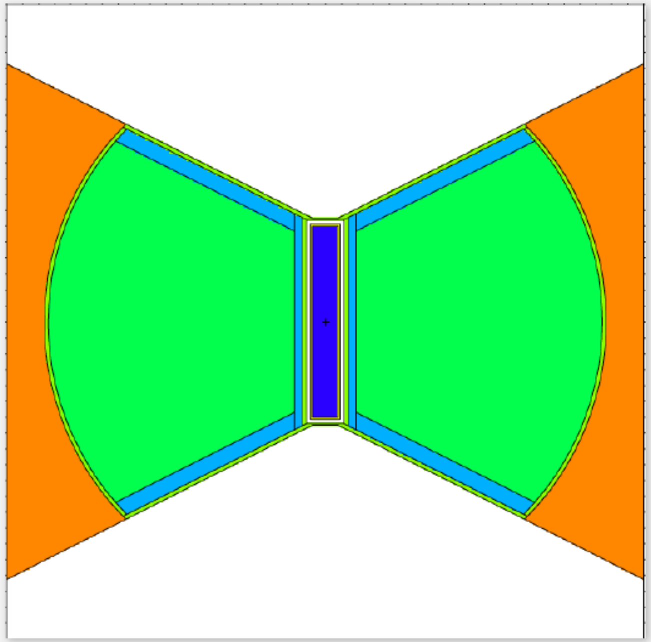
It works with any hydrogen-rich materials

Para-H_2 transparency window allows to collect neutrons from depth

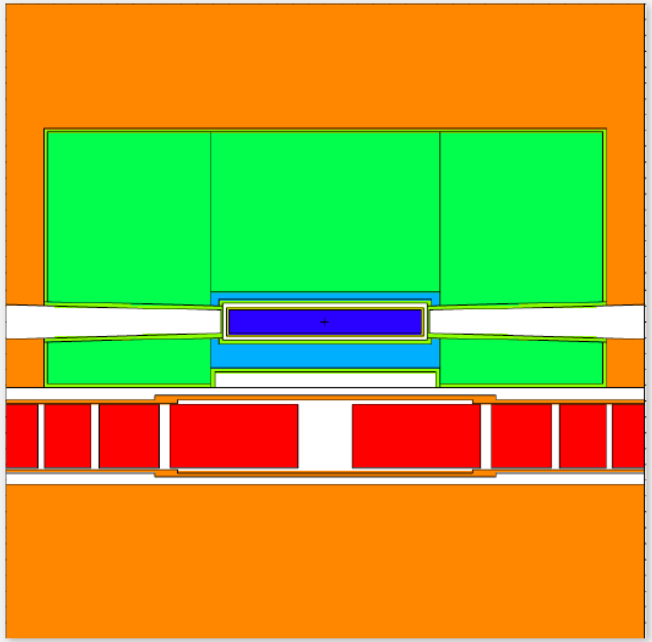
ESS Path to Low-Dimensional Moderators

Stand-Alone Tube Moderator

Hydrogen moderator of 3 cm height × 3 cm width × 24 cm length



View from above
Proton beam comes from the left



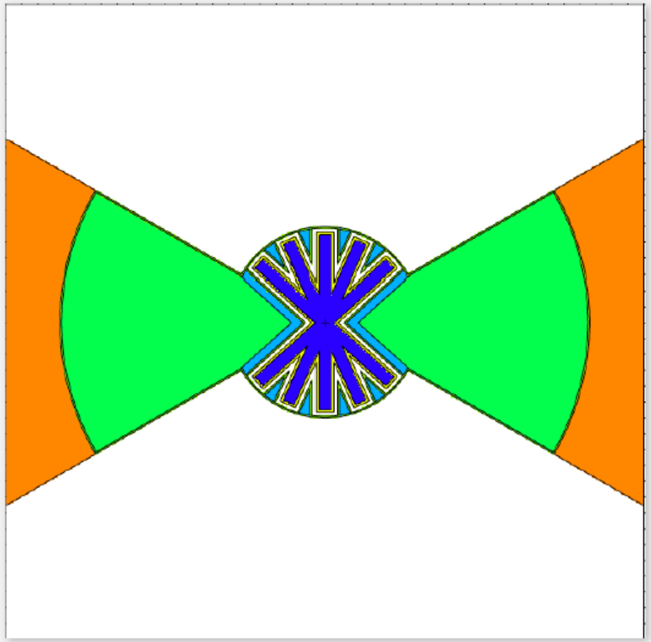
View in proton beam direction
Proton beam comes from behind

0-5 meV Brightness:	4.2

ESS Path to Low-Dimensional Moderators

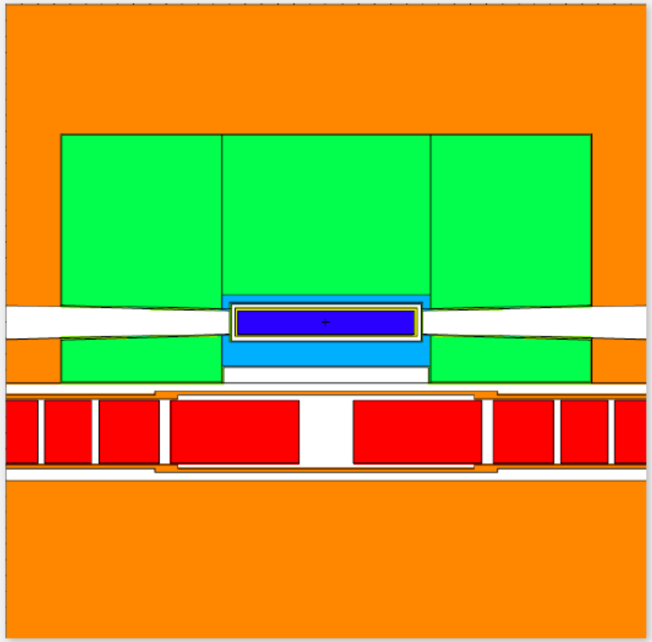
Starfish

5 tubes of 3 cm height × 1.5 cm width combined to serve wider extraction angles



View from above

Proton beam comes from the left



View in proton beam direction

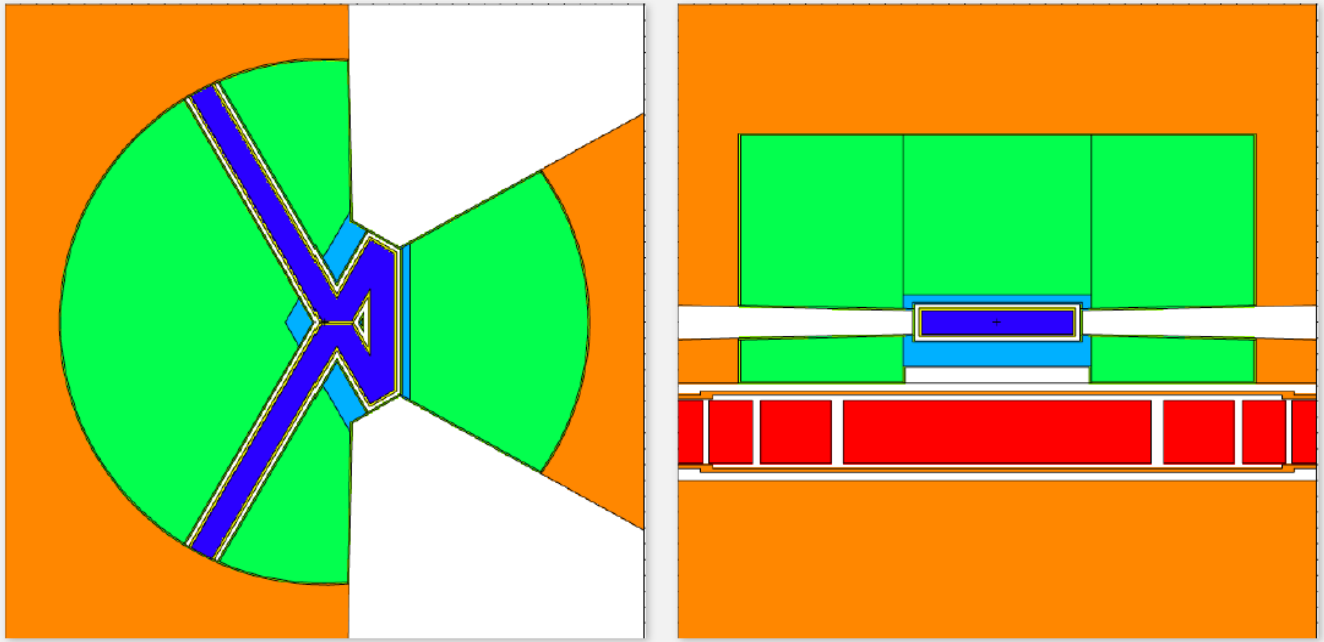
Proton beam comes from behind

0-5 meV Brightness:	3.6

ESS Path to Low-Dimensional Moderators

Diamond

3 tubes of 3 cm height × 3 cm width combined to serve wider extraction angles



View from above
Proton beam comes from the left

View in proton beam direction
Proton beam comes from behind

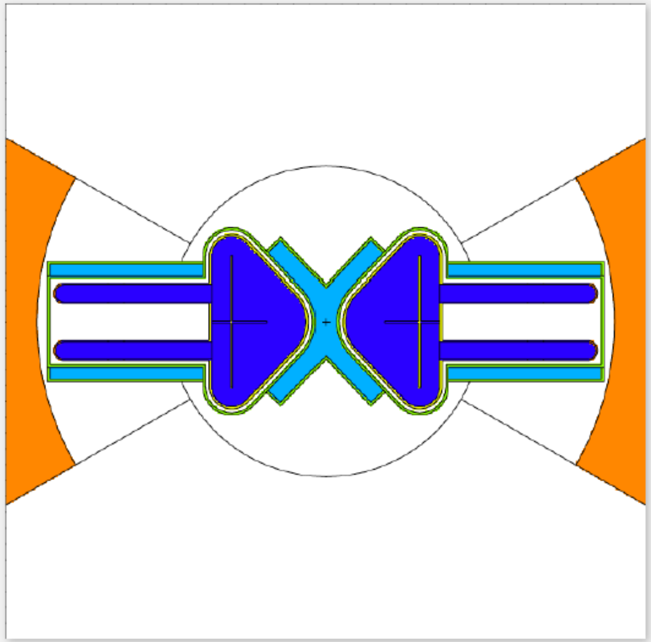
0-5 meV Brightness:	**4.1**

ESS Path to Low-Dimensional Moderators

EUROPEAN SPALLATION SOURCE

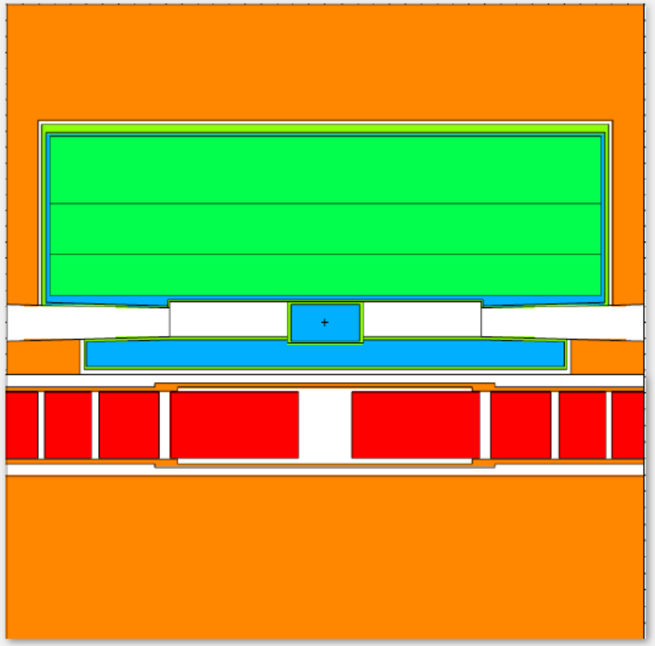
Mark I Butterfly Moderator

Hydrogen moderator of 3 cm height



View from above

Proton beam comes from the left



View in proton beam direction

Proton beam comes from behind

0-5 meV Brightness: **2.5**

ESS Path to Low-Dimensional Moderators

EUROPEAN SPALLATION SOURCE

Nuclear Inst. and Methods in Physics Research, A 925 (2019) 33–52

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

ELSEVIER

Design of the cold and thermal neutron moderators for the European Spallation Source

L. Zanini [a,*], K.H. Andersen [a], K. Batkov [a], E.B. Klinkby [a,b], F. Mezei [a], T. Schönfeldt [a,b], A. Takibayev [a]

[a] European Spallation Source ESS ERIC, PO Box 176, 22100 Lund, Sweden
[b] DTU Nutech, Technical University of Denmark, DTU Risø Campus, Frederiksborgvej 399, DK-4000, Roskilde, Denmark

ARTICLE INFO

Keywords:
Low-dimensional moderators
Source brightness
Parahydrogen
Water
Neutron beam extraction
Long pulse sources

ABSTRACT

At the European Spallation Source (ESS), neutrons will be generated by spallation induced by a 2-GeV proton beam on a tungsten target. ESS will have a grid of 42 beamports available for a variety of neutron scattering experiments. Neutron moderators will provide thermal and cold neutrons to the instruments, allowing bispectral beam extraction wherever needed.

The moderators were designed by adopting a holistic design approach that has considered brightness, brightness transfer and beam extraction constraints, resulting in a system with the following main features: low-dimensional moderators for enhanced brightness and maximum flux to the sample; a single moderator system placed above the spallation target; lateral shape of the moderators optimized for bispectral extraction. A moderator with a vertical extraction surface of 3 cm was chosen as result of the optimization process.

With all initial instruments pointing to the top moderator, and a beamport system that allows the possibility to extract neutrons from above and below the target, the adopted configuration opens the possibility to have different types of moderators below the target, so that other neutron beams of different intensity, or spectral shape, with respect to the ones delivered by the top moderator, could be envisaged, adding additional scientific opportunities to the facility without having the need to build a second target station.

UPGRADEABILITY

UPGRADEABILITY

EUROPEAN SPALLATION SOURCE

EXPANDING THE SCOPE

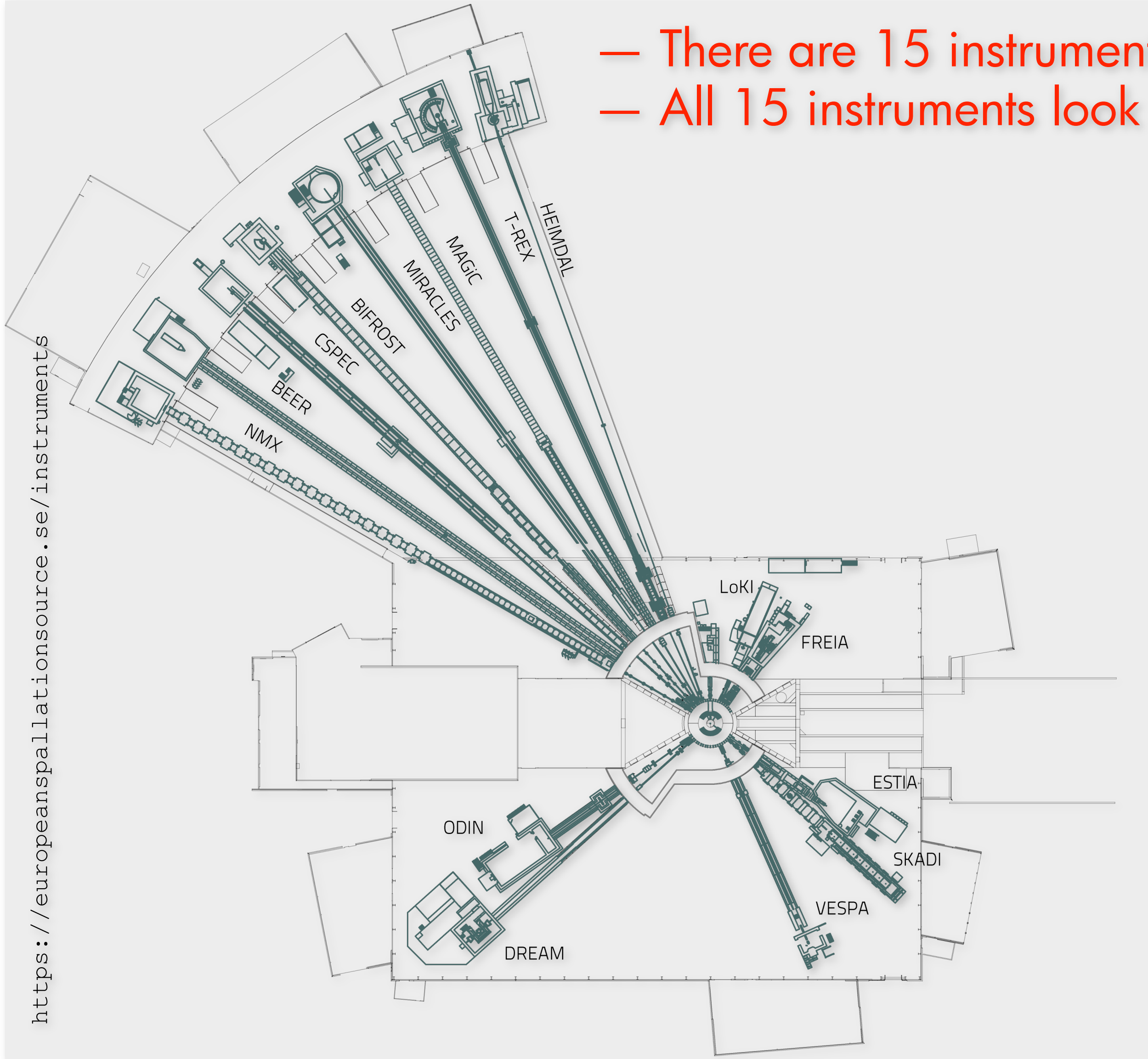
— Material irradiation station,
— Isotope production for medical use,
— Neutrino beams,
— Muon beams,
— Higgs factory?
— …

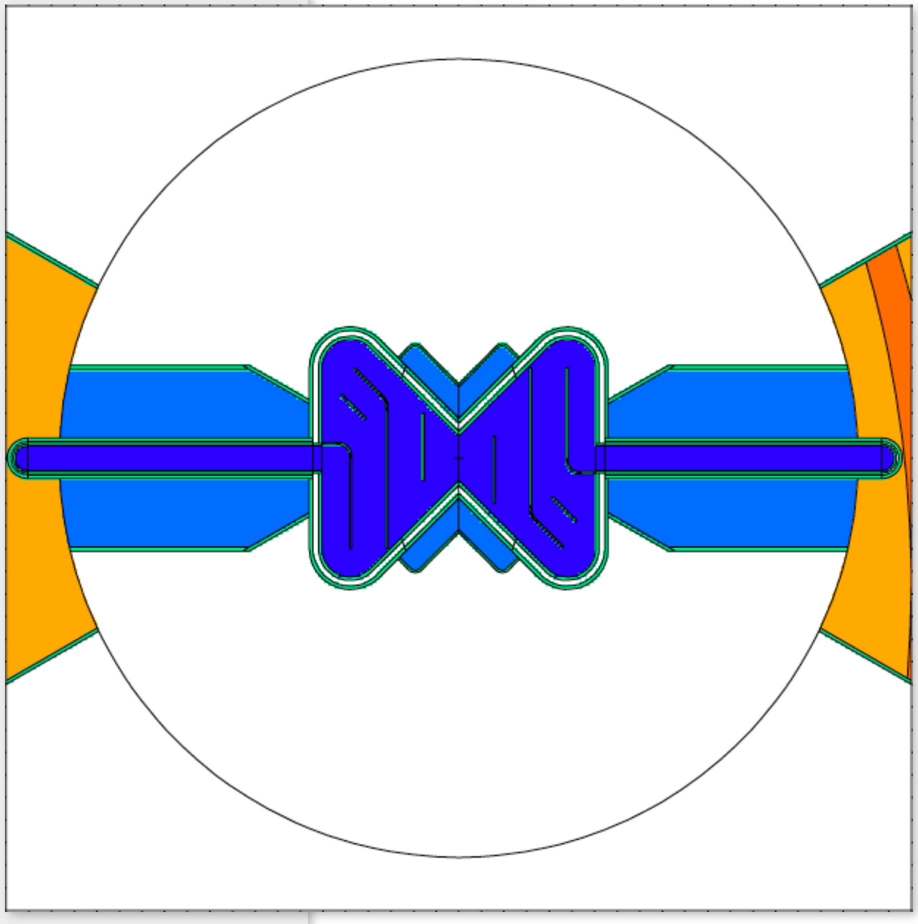
ESS IS A NEUTRON SCATTERING FACILITY FIRST AND FOREMOST!

— More instruments,
— More neutrons.

UPGRADEABILITY

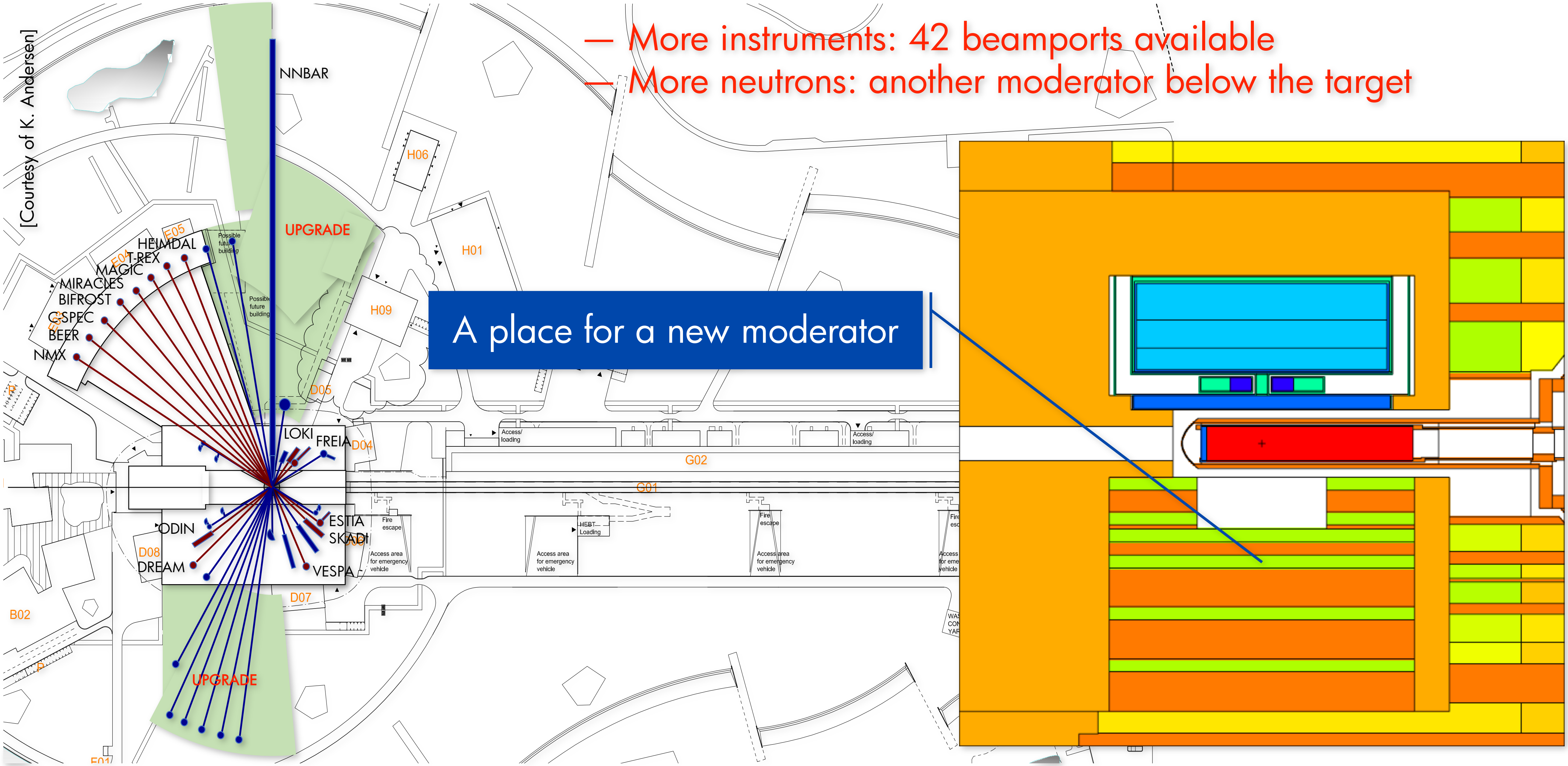
- There are 15 instruments (+ test beam line) currently under construction
- All 15 instruments look at the upper flat moderator





UPGRADEABILITY

- More instruments: 42 beamports available
- More neutrons: another moderator below the target



HIGHNESS PROJECT

EUROPEAN SPALLATION SOURCE

HighNess

THE AIM OF HIGHNESS PROJECT

High intensity

We aim at applications where the total number of neutrons is of higher value than the high brightness and low divergence achieved with a great performance by the upper quasi-low-dimensional moderator:

- NNBAR
- Condensed Matter (WP7)
- ...

Shifting the spectrum of delivered neutrons to longer wavelengths

First of all, we are looking for cold neutrons (the upper moderator is a bi-spectral neutron source).

Besides cold neutrons, we are looking for Very Cold and Ultra Cold neutrons.

The primary cold source is intended to serve instruments and secondary VCN and UCN sources.

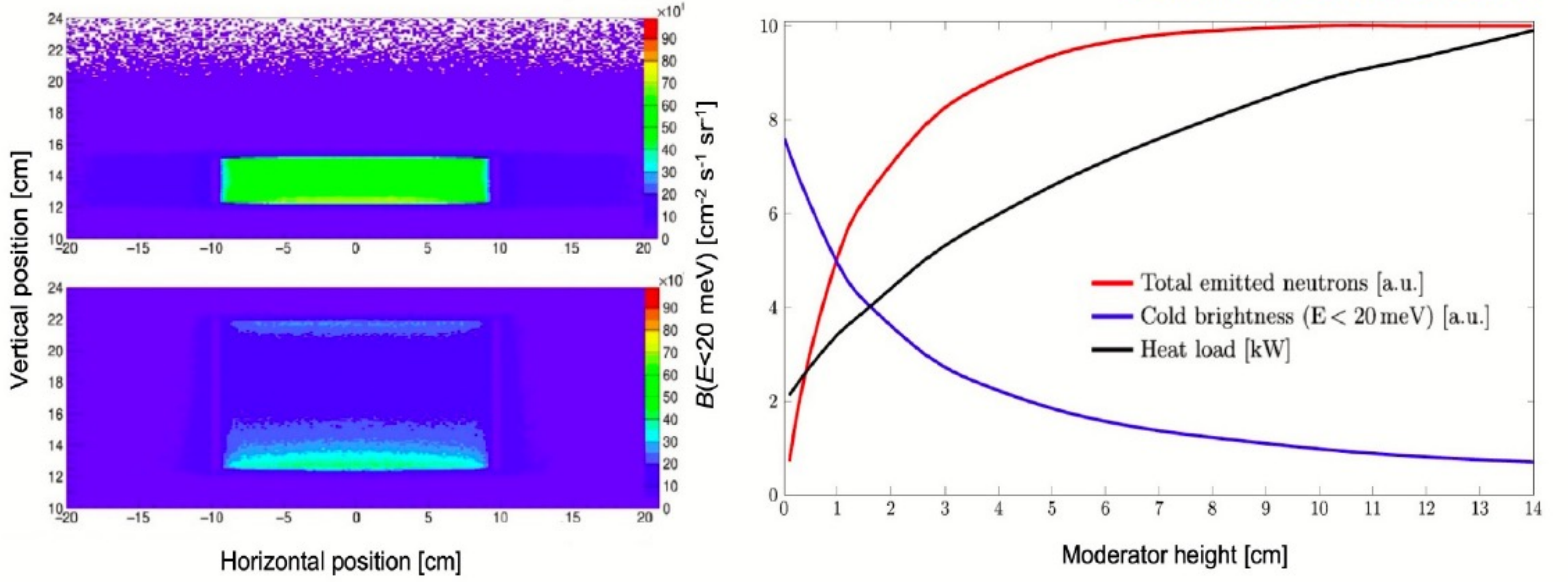
HighNESS is funded by the European Union Framework Programme for Research and Innovation Horizon 2020, under grant agreement 951782

HIGHNESS PROJECT: COLD SOURCE

HighNess

LH2 MODERATOR?

PARAHYDROGEN IS GOOD FOR BRIGHTNESS BUT NOT FOR INTENSITY!

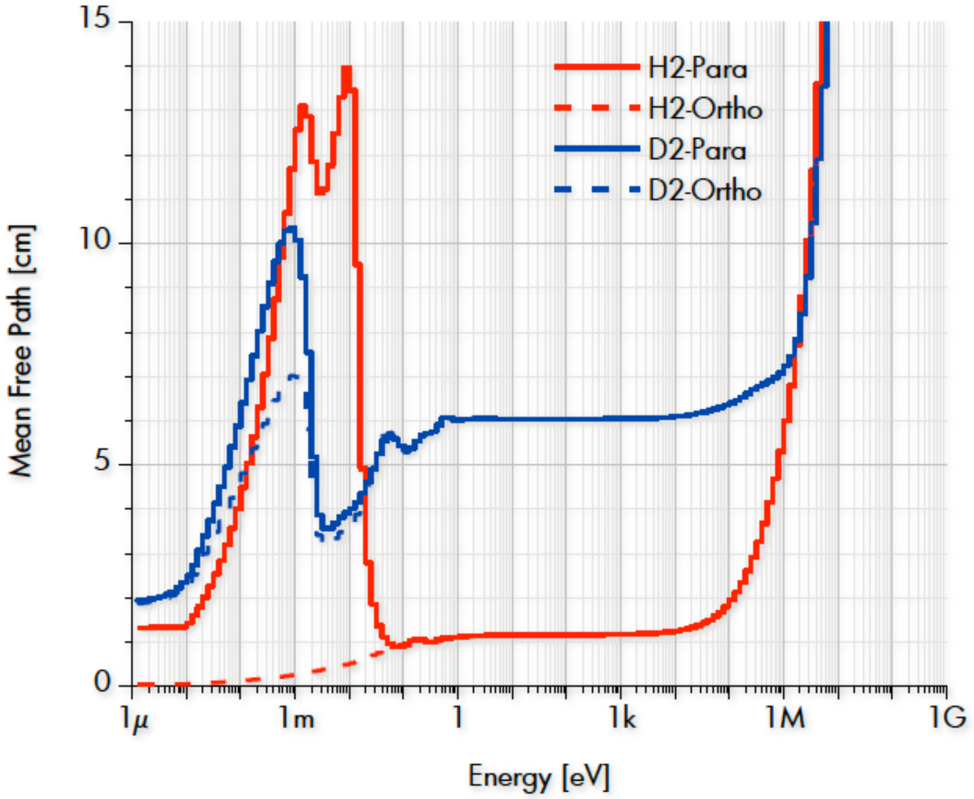


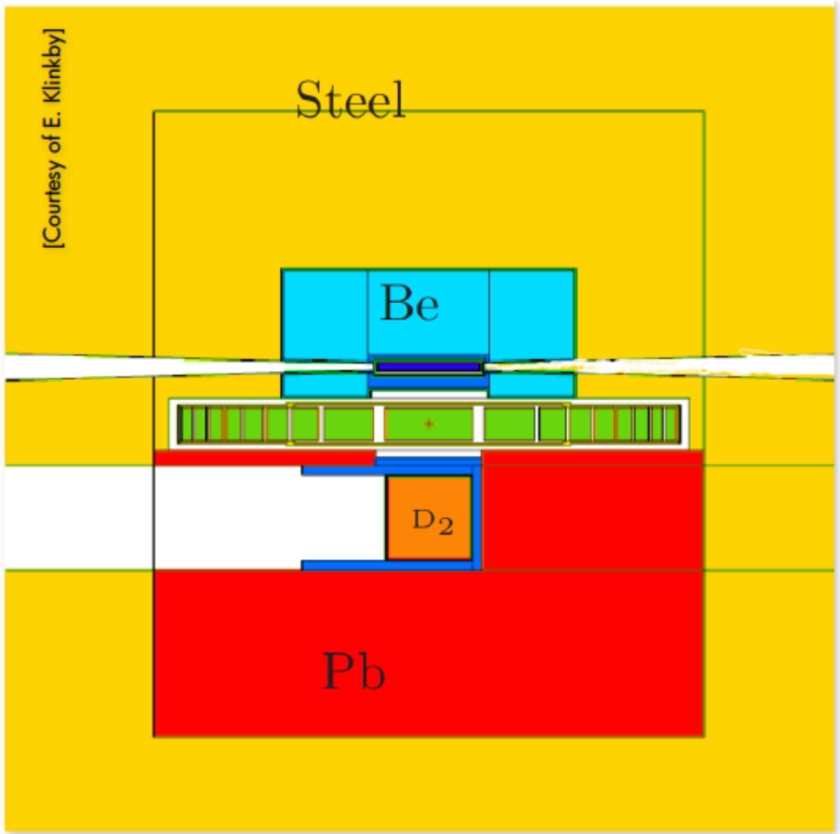
HighNESS is funded by the European Union Framework Programme for Research and Innovation Horizon 2020, under grant agreement 951782

HIGHNESS PROJECT: COLD SOURCE

HighNess

LD2 MODERATOR?



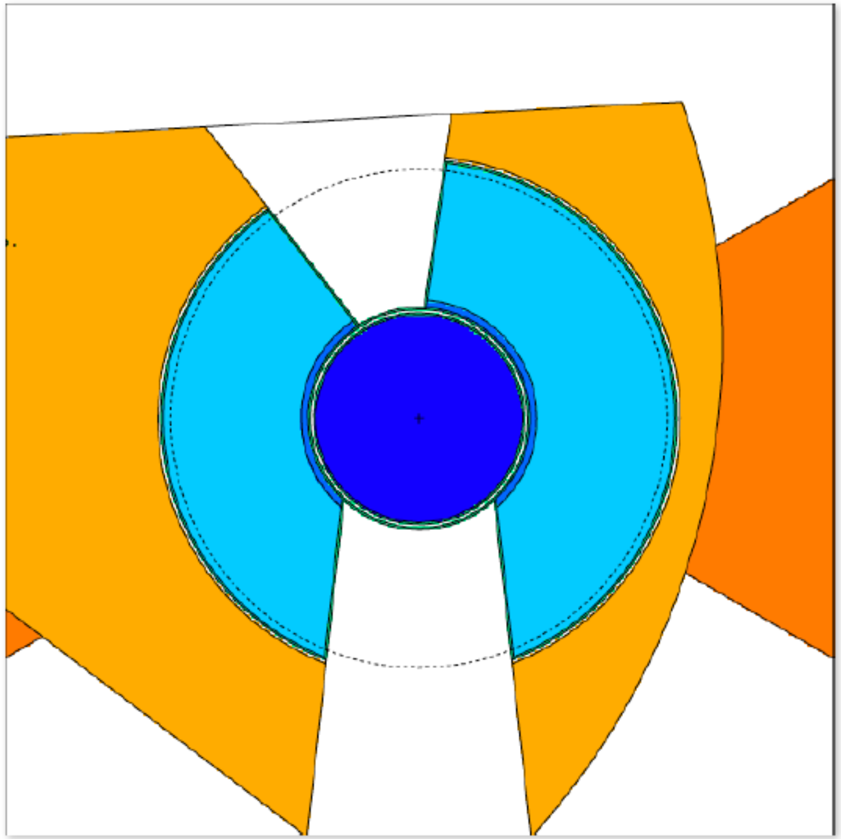


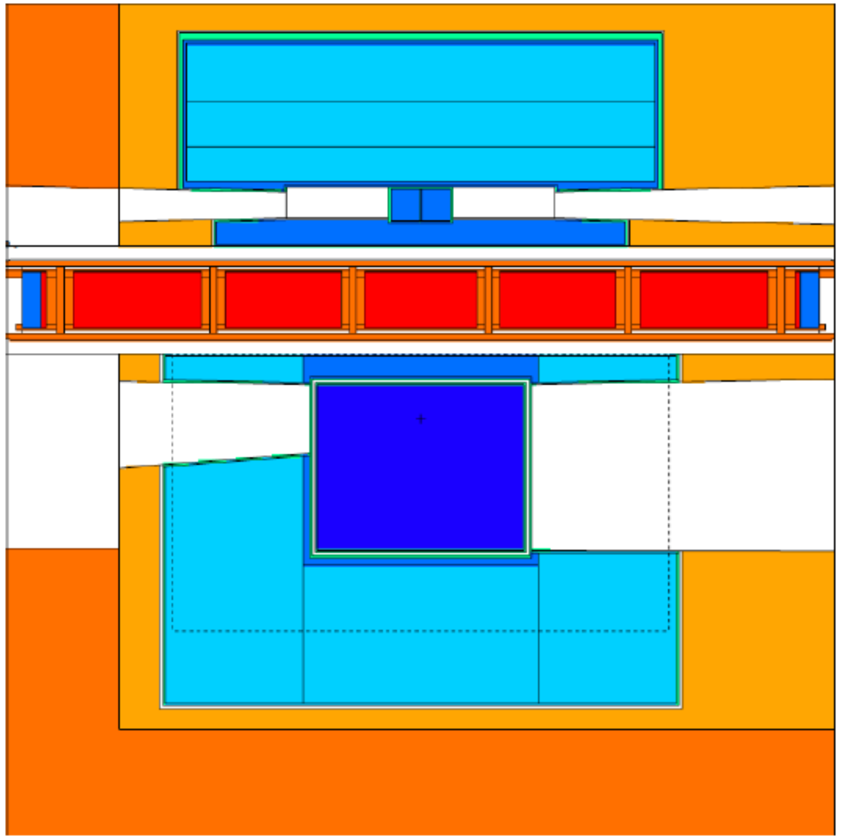
HighNESS is funded by the European Union Framework Programme for Research and Innovation Horizon 2020, under grant agreement 951782

HIGHNESS PROJECT: COLD SOURCE

HighNess

DESIGN AND OPTIMIZATION





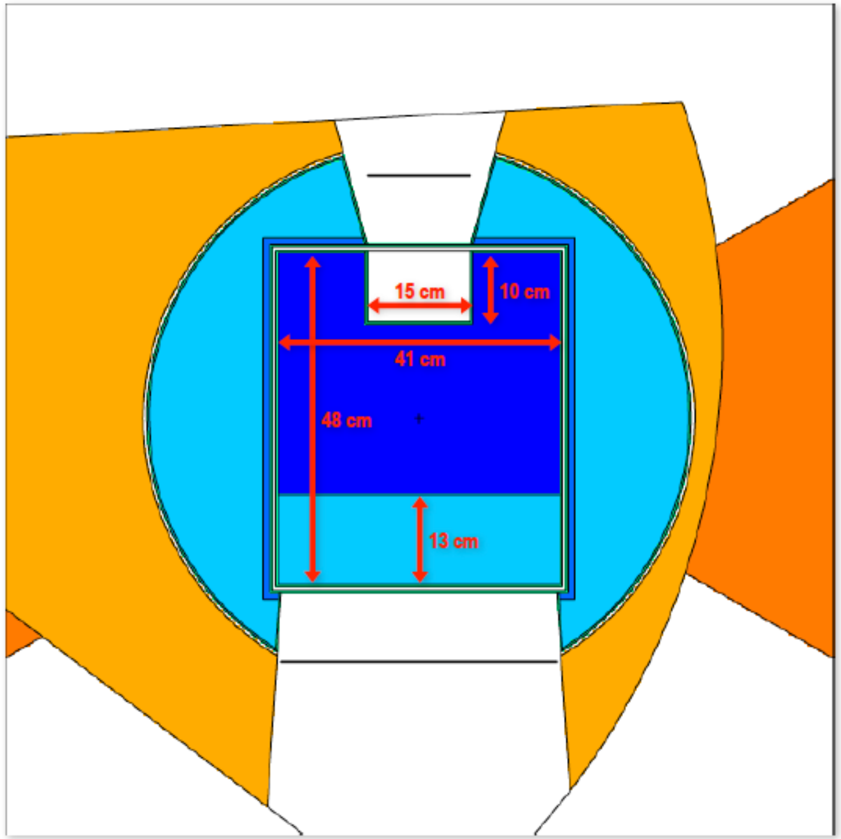
HighNESS is funded by the European Union Framework Programme for Research and Innovation Horizon 2020, under grant agreement 951782

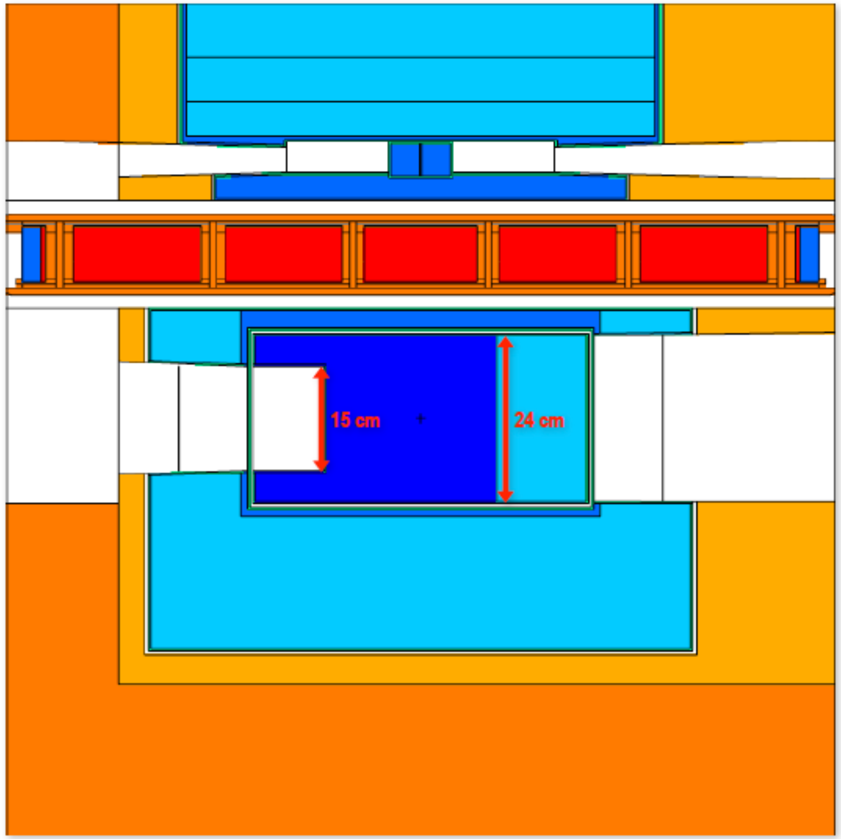
HIGHNESS PROJECT: COLD SOURCE

EUROPEAN SPALLATION SOURCE

HighNess

BASELINE SOLUTION





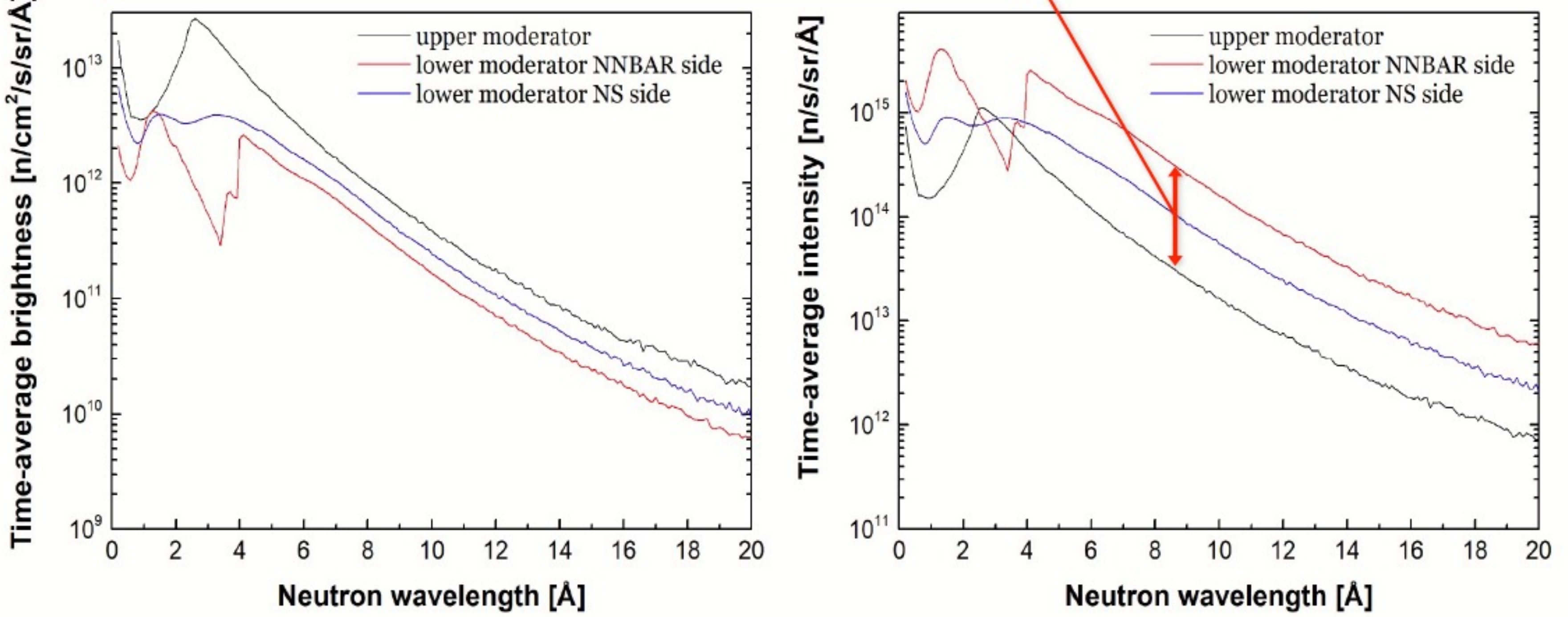
HighNESS is funded by the European Union Framework Programme for Research and Innovation Horizon 2020, under grant agreement 951782

HIGHNESS PROJECT: COLD SOURCE

HighNess

NEUTRON SPECTRA

ONE ORDER OF MAGNITUDE GAIN ABOVE 4 Å



HighNESS is funded by the European Union Framework Programme for Research and Innovation Horizon 2020, under grant agreement 951782

HIGHNESS PROJECT: COLD SOURCE

EUROPEAN SPALLATION SOURCE

HighNess

WHAT WE LEARNED

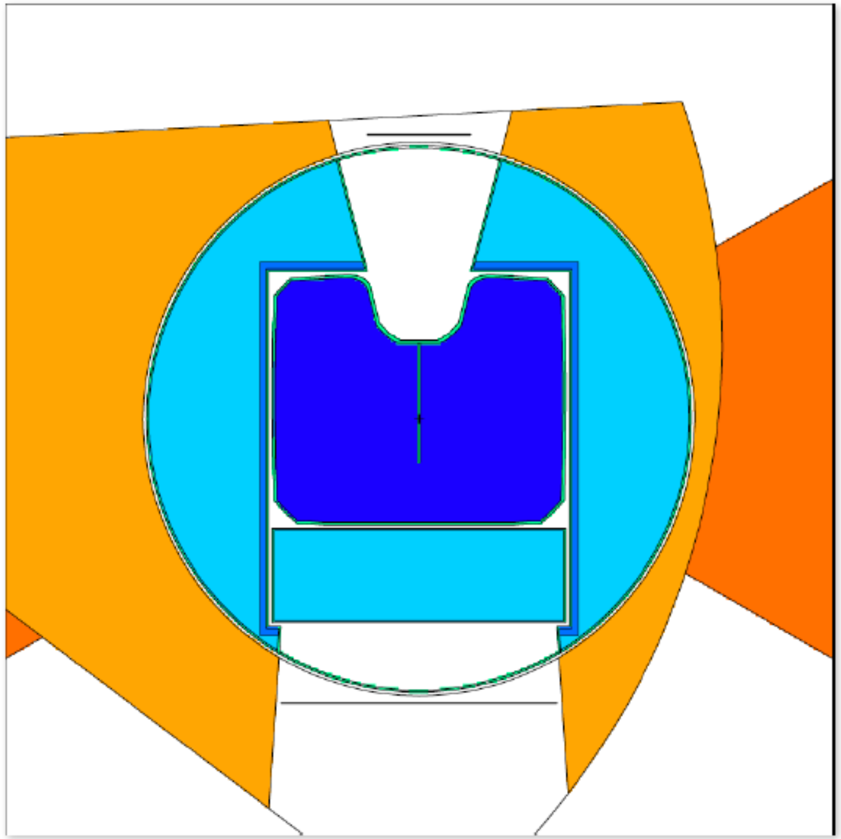
Shape	Rectangular is better than cylindrical
Re-entrant hole (REH)	WP7 FOM: about 30% gain
Cold Be filter	NNBAR FOM: about 30% gain
Premoderator	Unlike the upper moderator, water layer between cold moderator and reflector is essential
Ortho/para ratio	Unlike the upper moderator, the ratio is not crucial but 100% ortho-D2 gives about 5-10% gain comparing with normal (2:1 ortho/para ratio) D2
Al content	Unlike the upper moderator, Al content is important: around 4% loss in performance per 1%vol. of Al

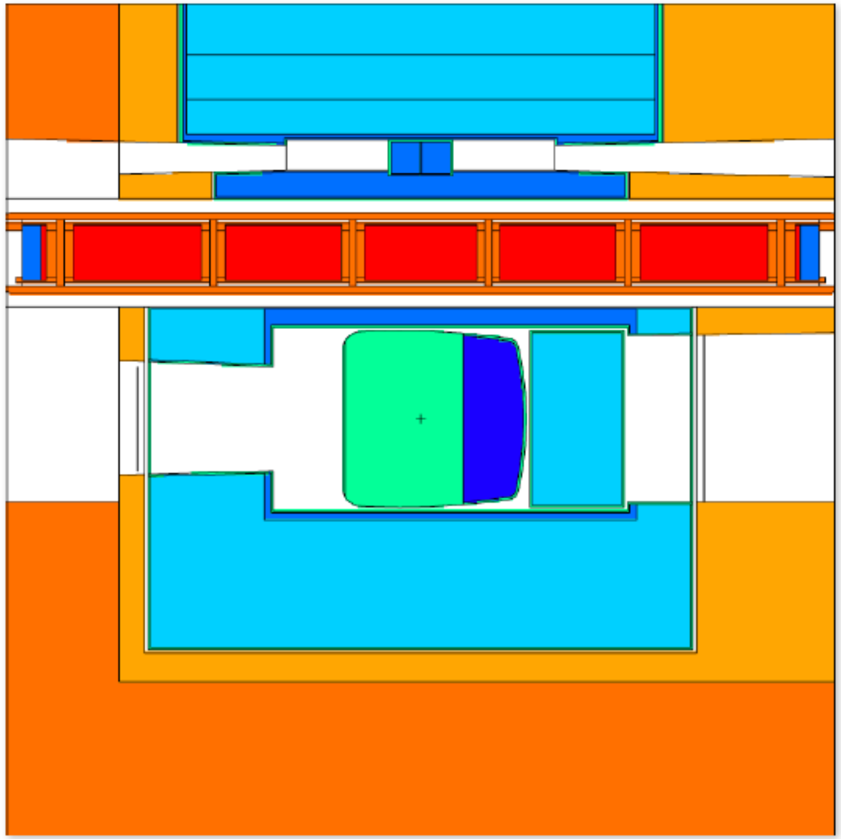
HighNESS is funded by the European Union Framework Programme for Research and Innovation Horizon 2020, under grant agreement 951782

HIGHNESS PROJECT: COLD SOURCE

HighNess

FROM NEUTRONICS TO ENGINEERING



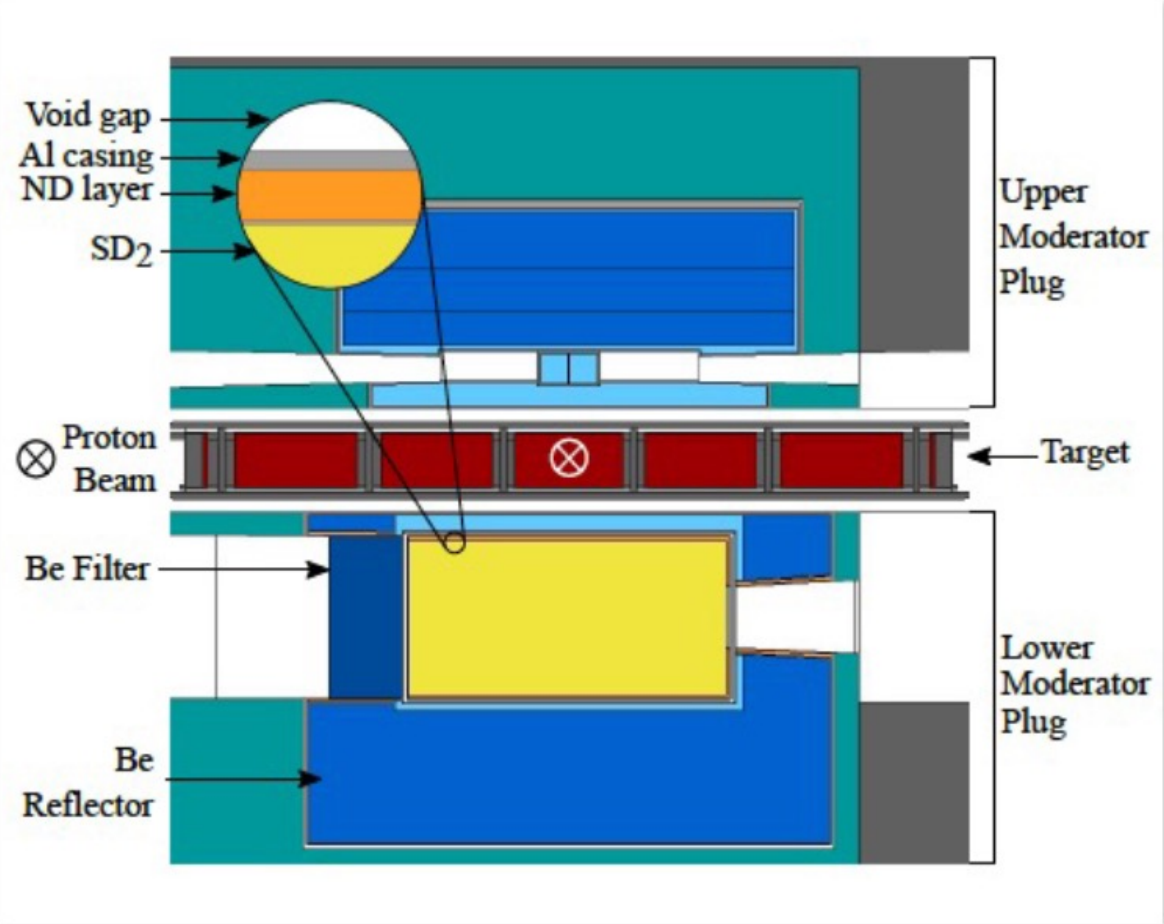


HighNESS is funded by the European Union Framework Programme for Research and Innovation Horizon 2020, under grant agreement 951782

HIGHNESS Project: VCN Source

EUROPEAN SPALLATION SOURCE

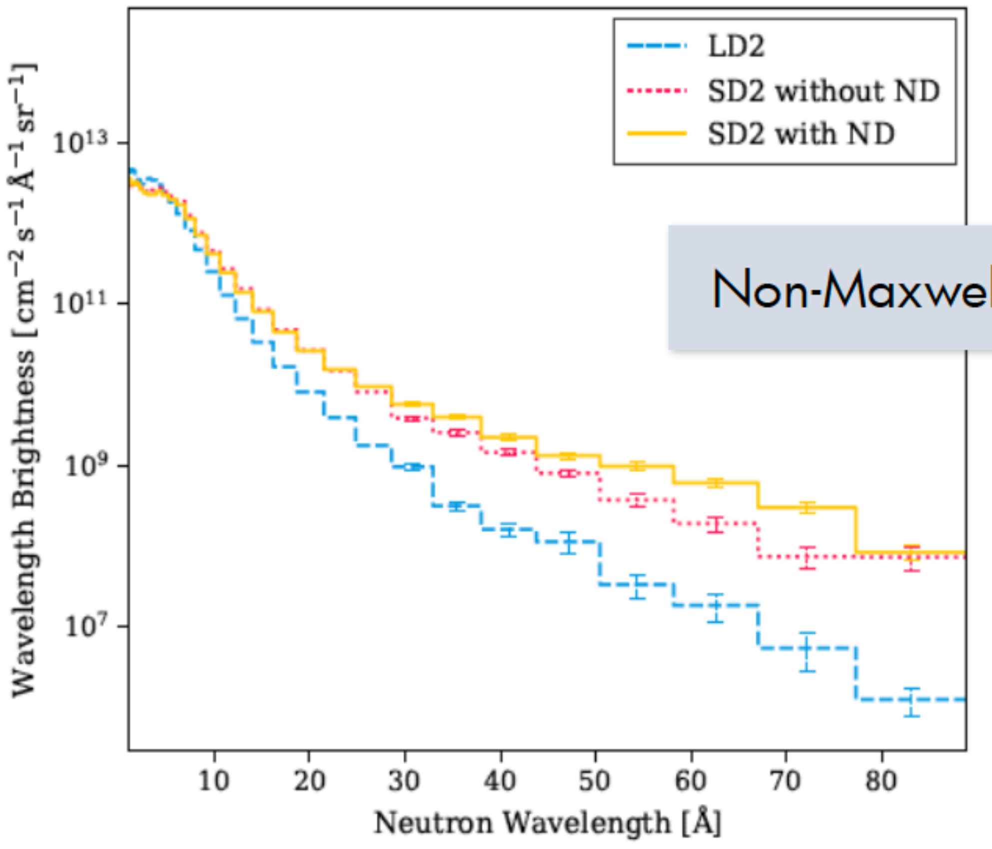
VERY COLD SOURCE



LD2 replaced by SD2

HIGHNESS PROJECT: VCN SOURCE

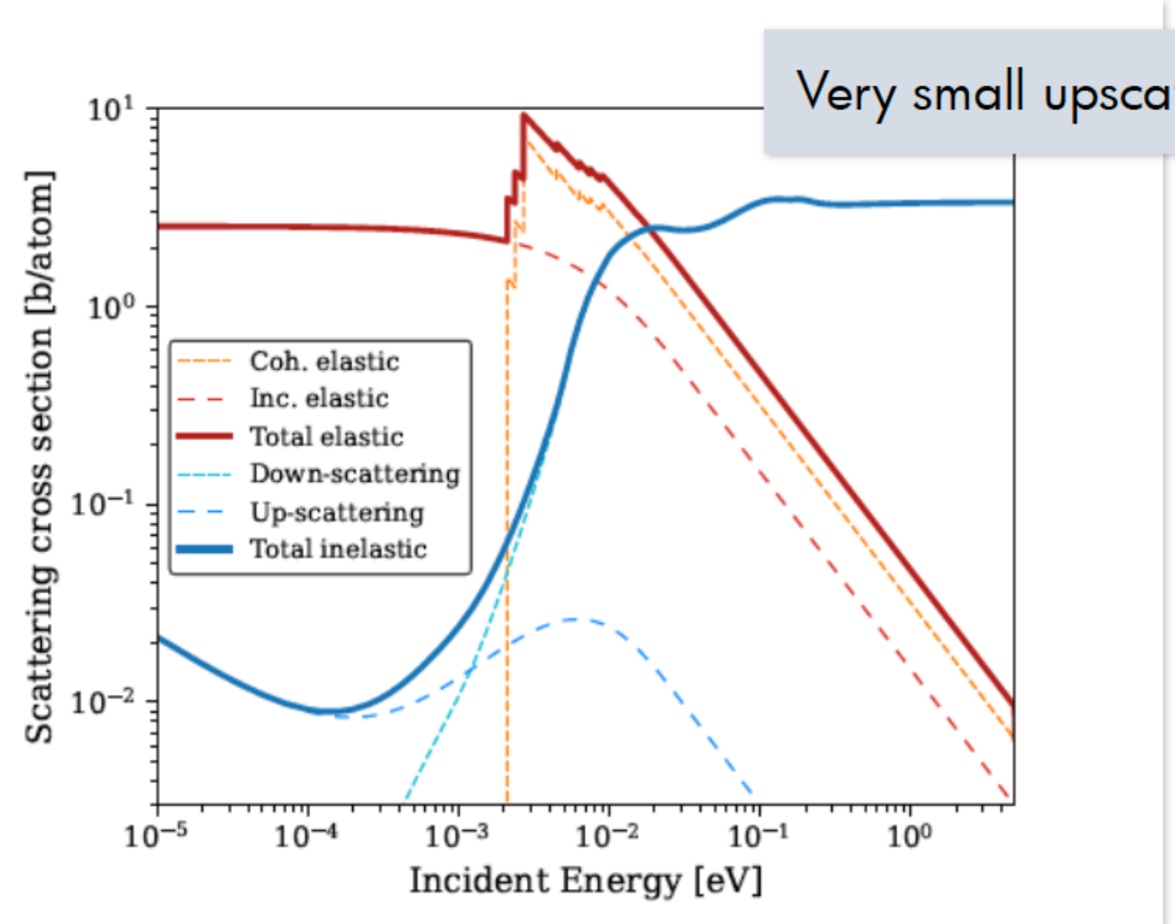
VERY COLD SOURCE



Non-Maxwellian cold tail of neutron spectrum

HIGHNESS Project: VCN Source

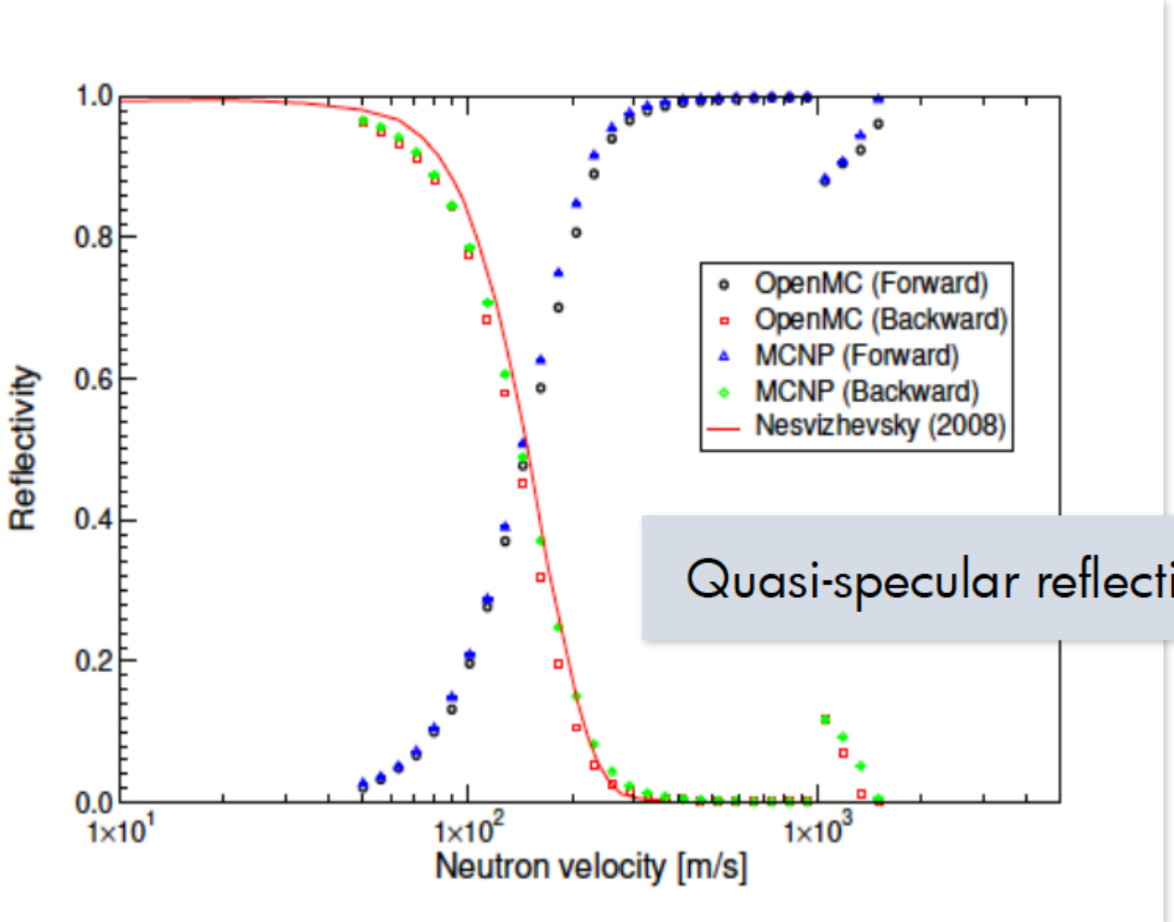
VERY COLD SOURCE



Very small upscattering cross-section of SD2

HIGHNESS Project: VCN Source

VERY COLD SOURCE

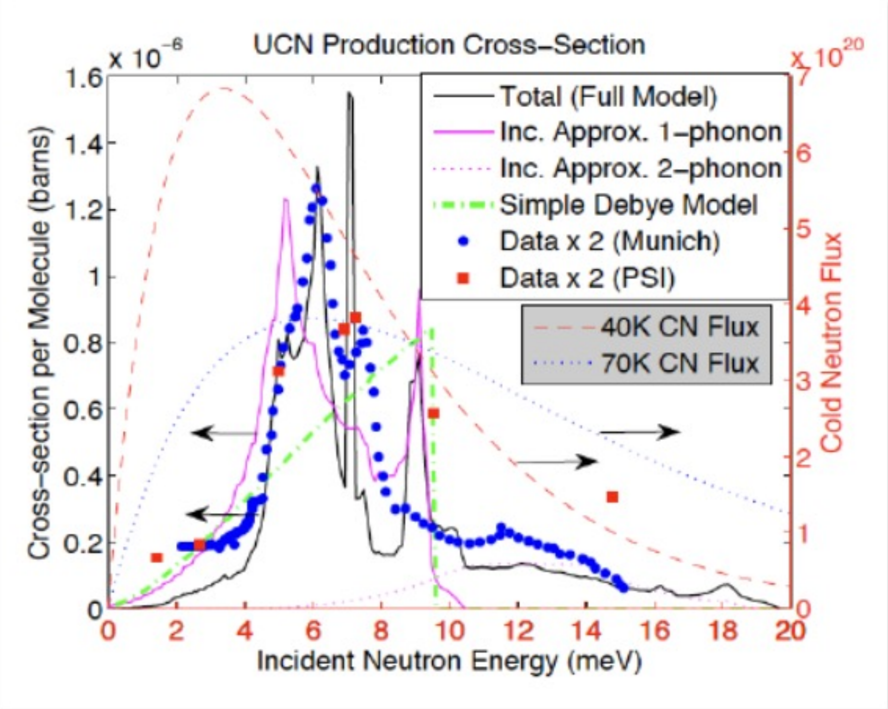


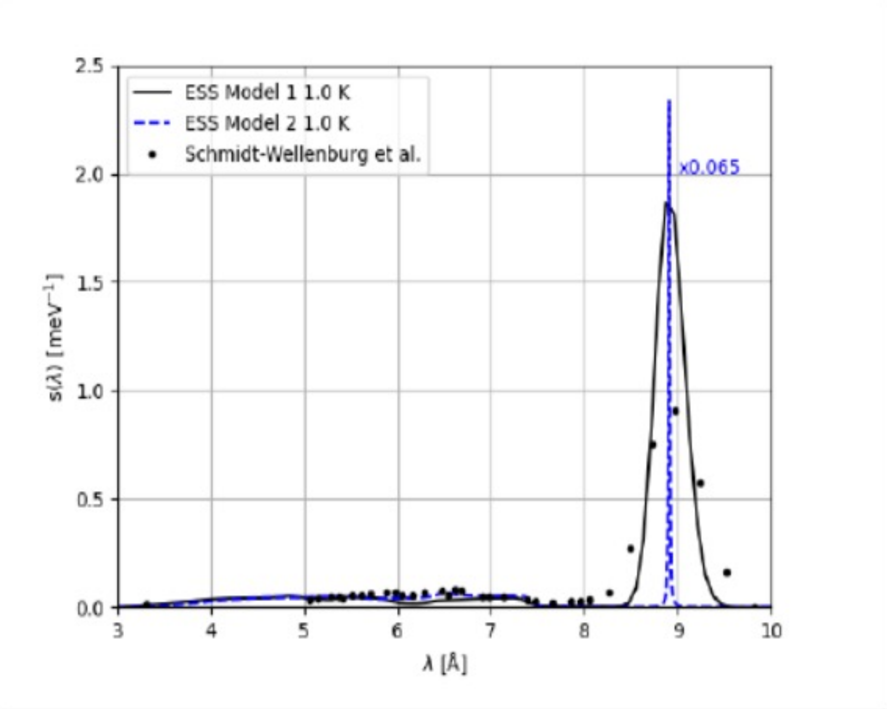
Quasi-specular reflection in ND kicks off > 20 Å

HIGHNESS Project: UCN Source

ULTRA COLD SOURCE

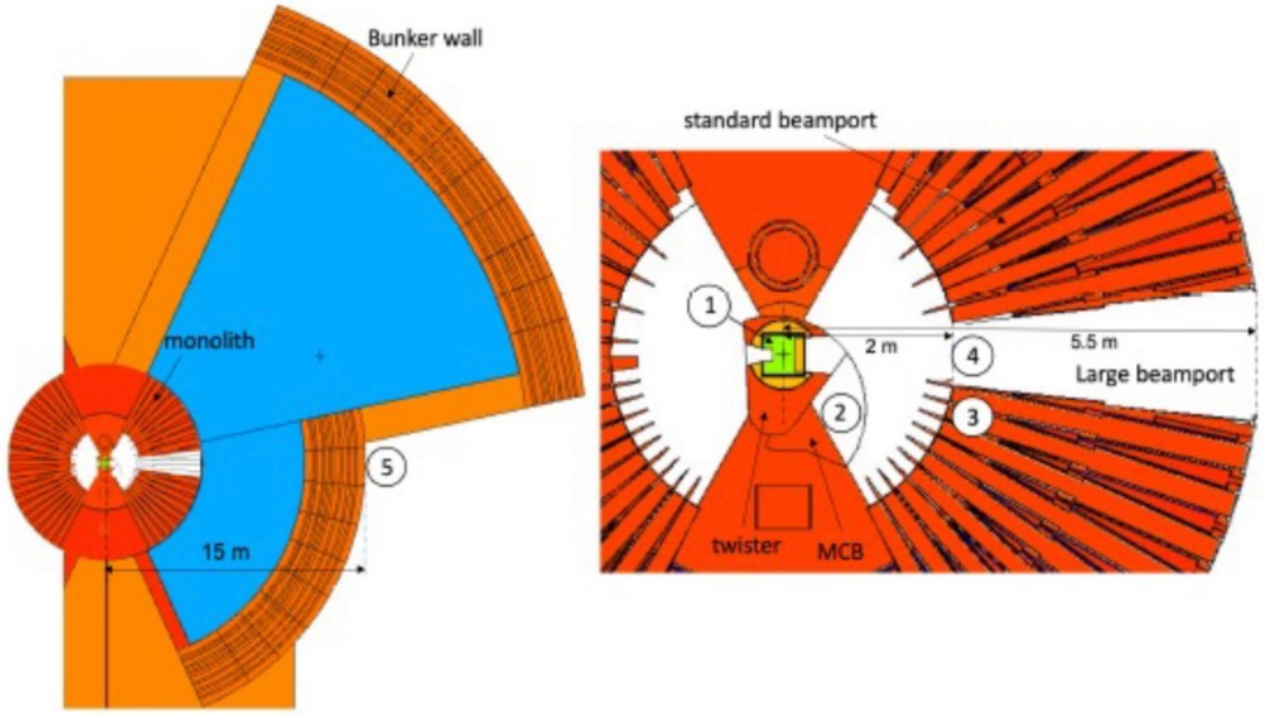
Materials





ULTRA COLD SOURCE

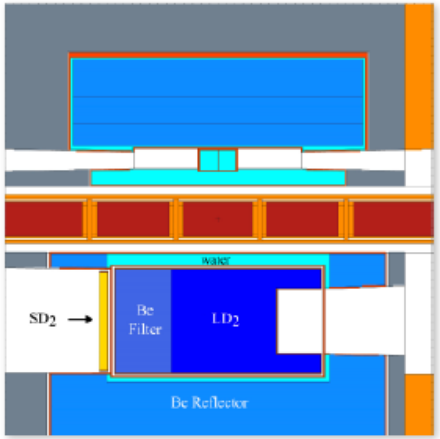
Locations

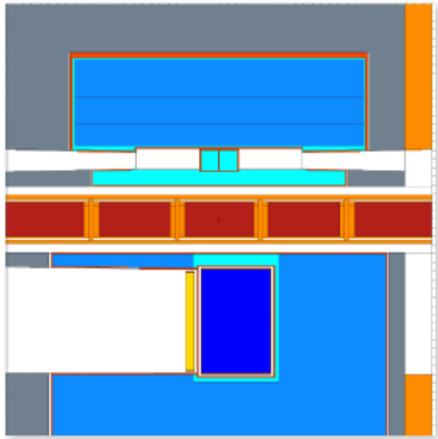


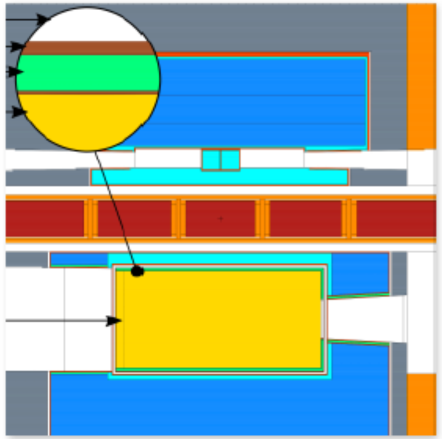
HIGHNESS PROJECT: UCN SOURCE

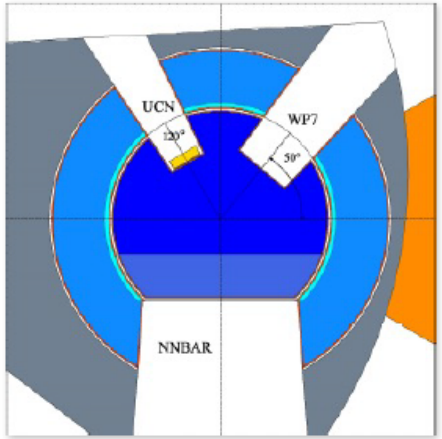
ULTRA COLD SOURCE

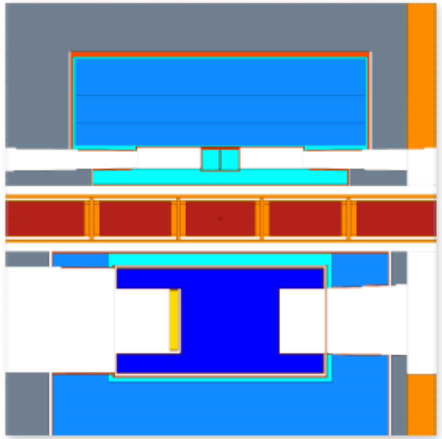
SD2 | Twister







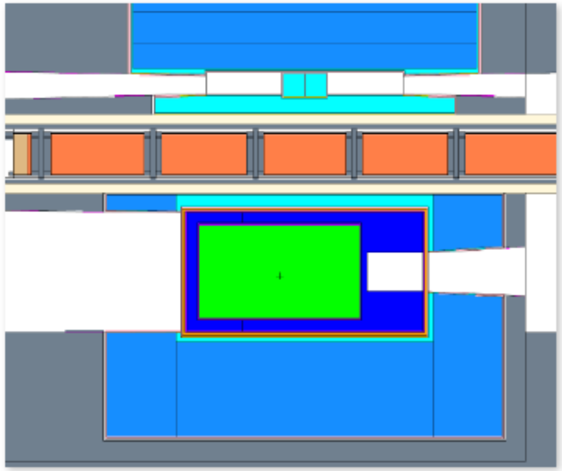


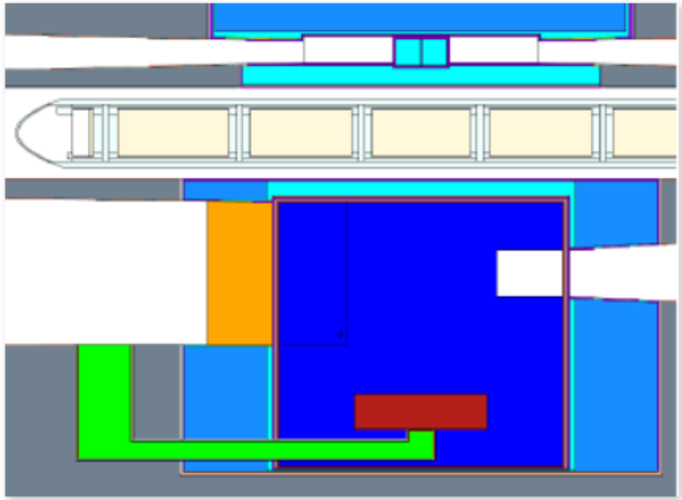


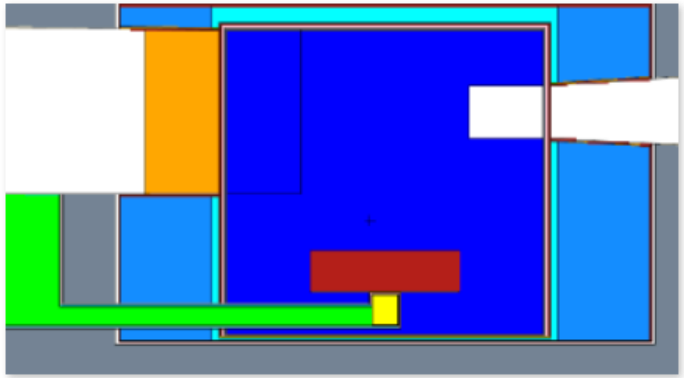
HIGHNESS Project: UCN Source

ULTRA COLD SOURCE

He II | Twister



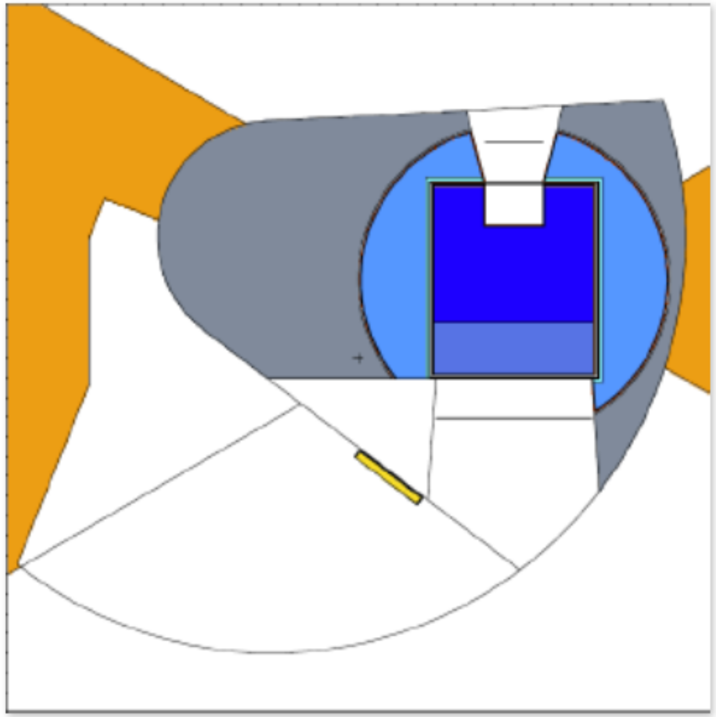




HIGHNESS Project: UCN Source

ULTRA COLD SOURCE

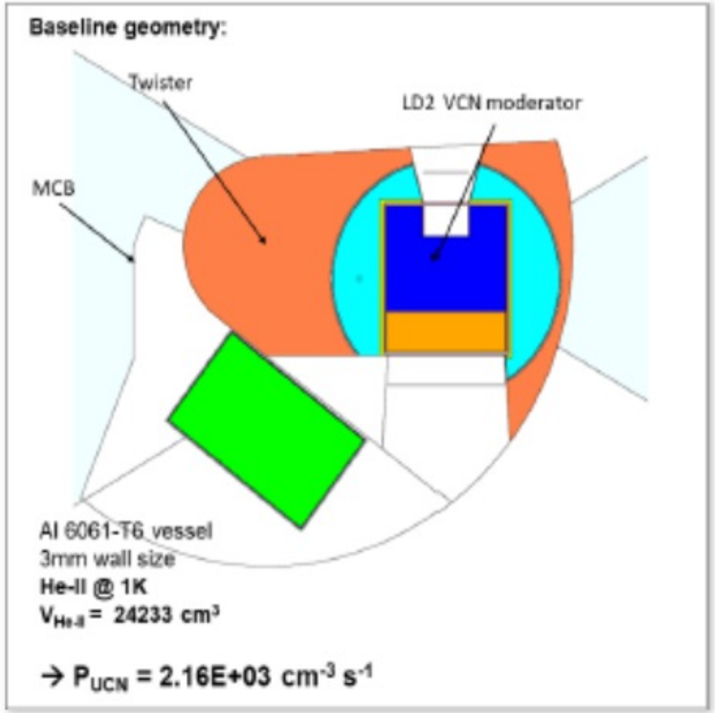
SD2 | Moderator Cooling Block

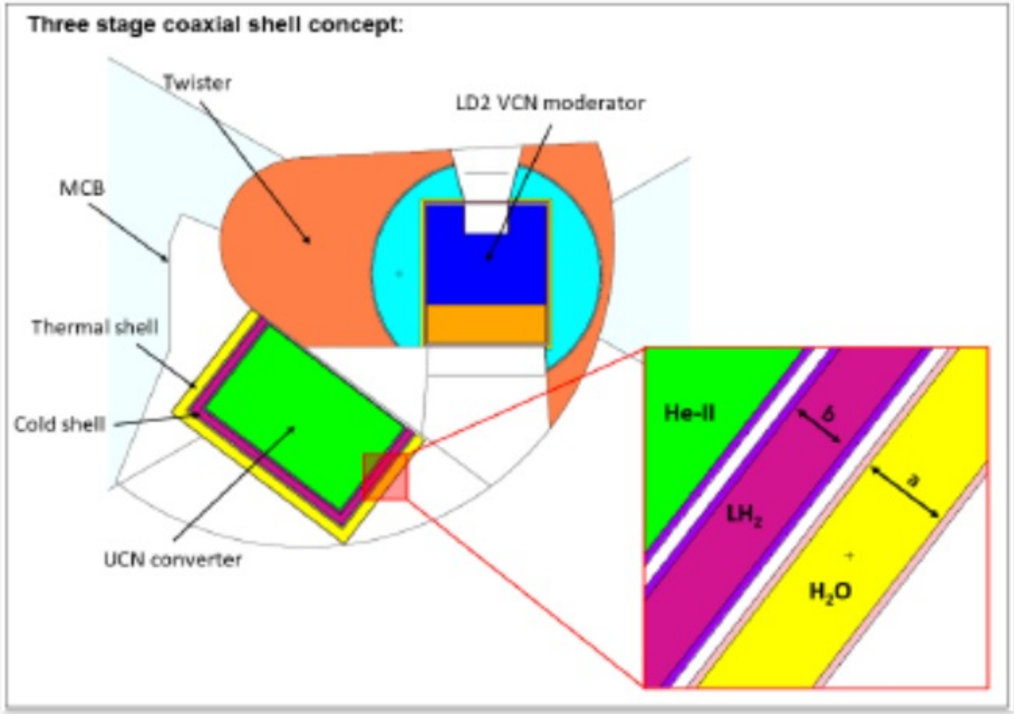


HIGHNESS Project: UCN Source

ULTRA COLD SOURCE

He II | Moderator Cooling Block

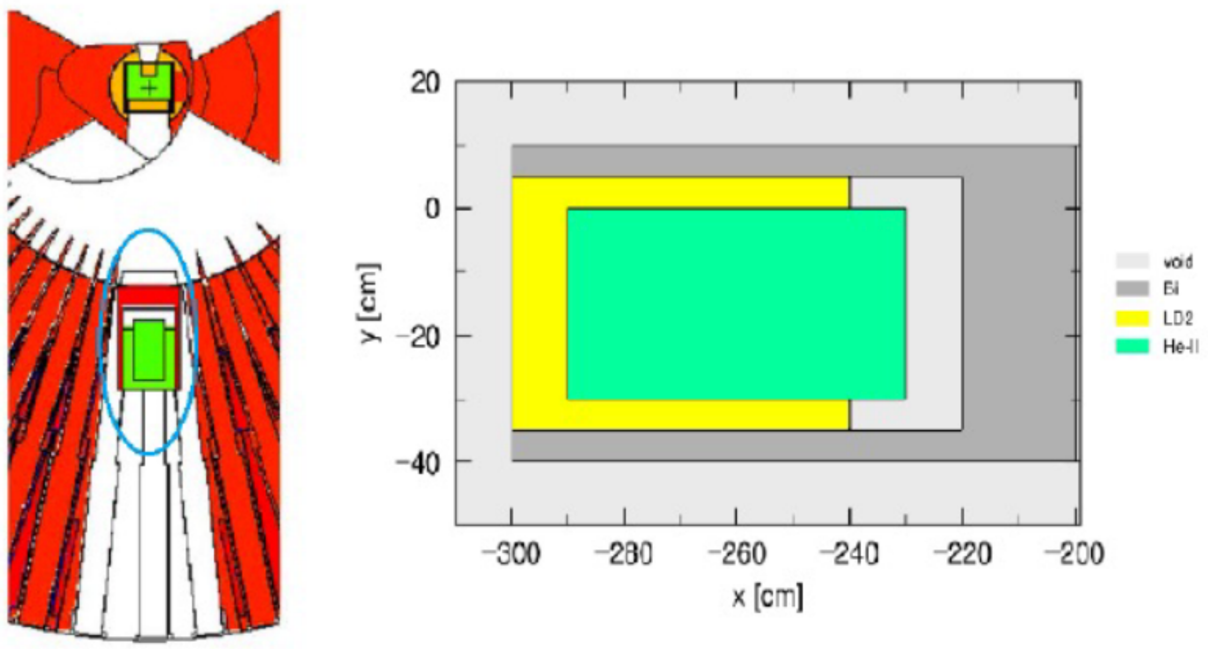




HIGHNESS Project: UCN Source

ULTRA COLD SOURCE

He II | NNBAR Beamport



HIGHNESS PROJECT: INNOVATIVE MATERIALS

EUROPEAN SPALLATION SOURCE

DTU HighNess

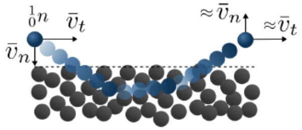
Nanodiamonds in MCNP

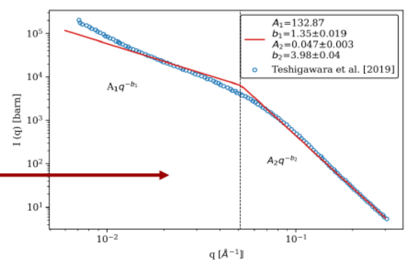
[Courtesy of N. Rizzi]

Total microscopic per-atom cross section

$$\sigma_{SANS}(k_0) = \int I(q)d\Omega = \int_0^{2\pi} d\phi \int_0^{\pi} I(q)d\theta$$

$$\sigma_{SANS}(k_0) = \frac{2\pi}{k_0^2}\int_0^{2k_0} I(q)qdq$$



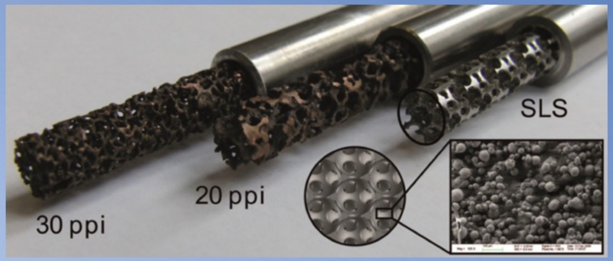


SANS experimental $I(q)$ in absolute units = $\frac{d\sigma}{d\Omega}(q)$ microscopic differential per-atom cross section with units barn sr^{-1}

HighNess

Conventional vs. SLS (3D printed) foams

- SLS has better heat extraction in some applications. May be prohibitively expensive with beryllium due to toxicity measures. Additionally, the outer surface is left porous after fabrication.
- With conventional foaming-agent production, density and porosity can be tuned homogeneously. This is a more mature technology and may be more feasible for beryllium.



[6]

[Courtesy of B. Folsom]

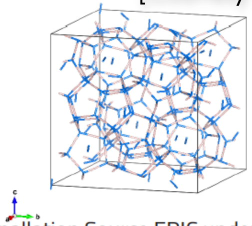
Motivations

Clathrate hydrates are ice-like compounds having a cage structure. Small molecules such as methane can be enclathrated in the cage, stabilising the structure.

- Tetrahydrofuran (THF/TDF)-containing clathrate hydrates: low energy modes
- Oxygen-containing clathrate hydrates: neutron inelastic magnetic scattering

[Courtesy of S. Xu]

- large Bragg cutoff wavelength (2 nm)
- small absorption of deuterium



This work was funded by HighNESS project at European Spallation Source ERIC under HORIZON 2020 grant agreement ID: 951782.

SUMMARY

WHAT IS ESS?

— ESS will be the world's most powerful "neutron microscope".

SELECTED DESIGN FEATURES

— A moderator system based on a quasi-low-dimensional moderator concept,
— Initial 15-instrument suite served by one high-brightness flat bi-spectral moderator.

UPGRADEABILITY

— Uniform grid of 42 beamports: more instruments,
— A place for a second neutron source: more neutrons.

DEVELOPMENT OF A SECOND NEUTRON SOURCE

— A high-intensity LD2 moderator to serve instruments and secondary VCN and UCN sources,
— A number of VCN and UCN source designs,
— Innovative materials (metal hydrides, nanodiamonds, clathrates, etc.) are under ongoing investigation.