HighNess

Very Cold and Ultra Cold sources for ESS

Luca Zanini

for HighNESS WP4 team and collaborators: E. Dian, I. Marquez-Damian, E. Klinkby, Z. Kokai, B. Rataj, N. Rizzi, V. Santoro, A. Takibayev, R. Wagner

2.2.2022, HighNESS/LENS workshop on Very Cold and Ultra Cold Sources for ESS

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

CONTENTS

- ESS high-brightness upper moderator
- Adding new possibilities: the goals of HighNESS sources
- Lower high-intensity cold moderator
  - The main HighNESS moderator, intended also to serve UCN and VCN secondary sources
- Basic concepts and possible locations of the VCN and UCN sources
  - Important input for WG discussions

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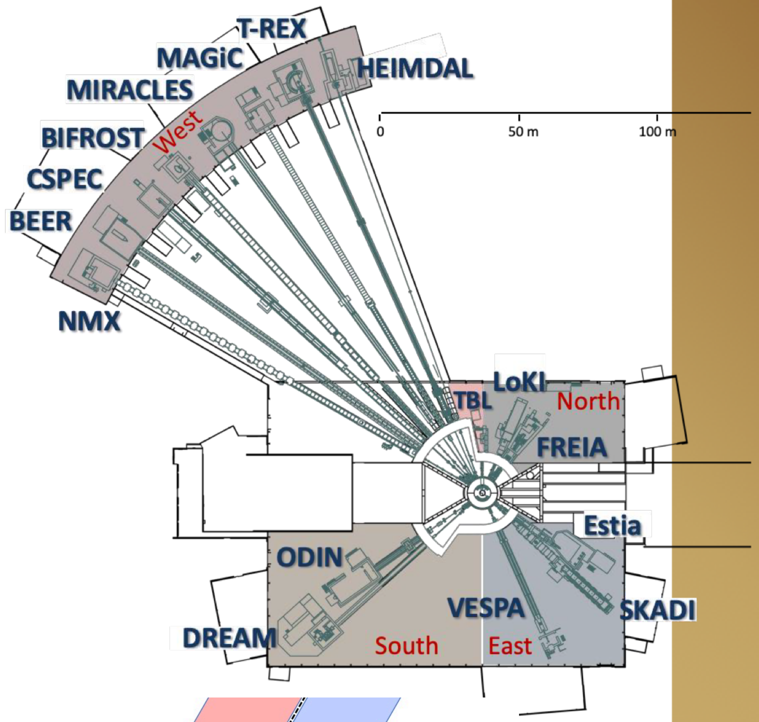
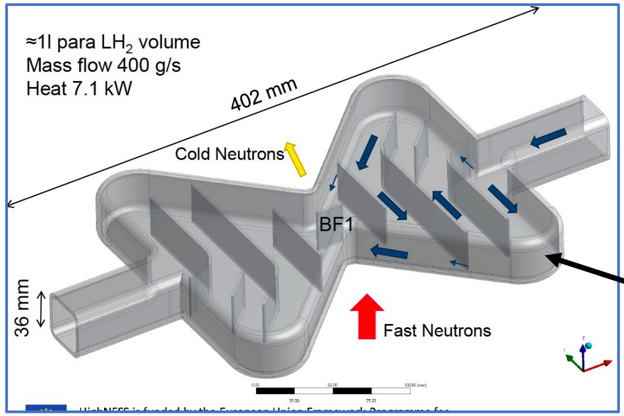
A few words about the upper moderator

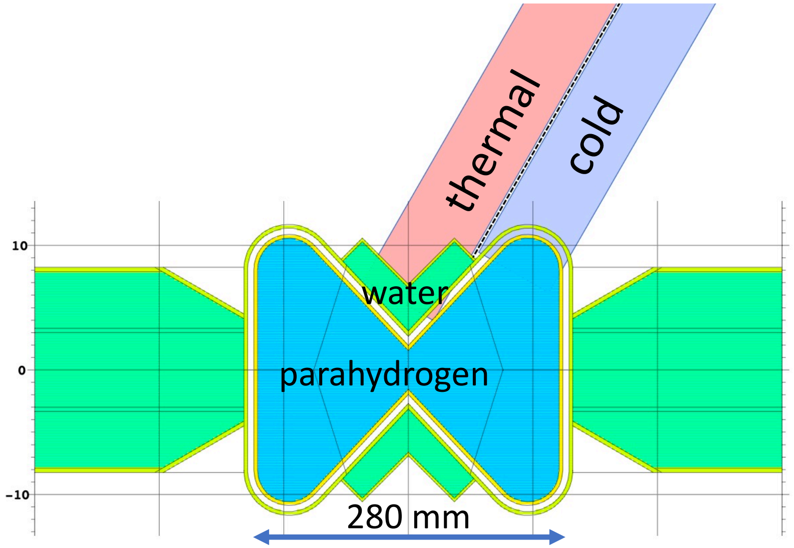
HighNess

- High brightness bispectral (thermal-cold) source available to all 42 beamports of ESS
- Serving all 15 instruments of initial ESS instrument suite.
- Single moderator system placed above the spallation target





3 cm height



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Research ar… …eement 951782

See Y. Bessler presentation

HighNESS aims at complementing the upper source in two different aspects

High Intensity

We look at applications where total delivery of neutrons is of higher value than the high brightness, low-divergence achieved with great performance by the upper moderator

We still aim at high brightness, but the priority is for applications where intensity is more important

Higher intensity means larger emission surface and bigger moderator

Shift the spectrum of delivered neutrons to longer wavelengths

The upper moderator is a bispectral thermal-cold source

Thermal neutrons are not considered in HighNESS.

In HighNESS, besides cold neutrons, we are looking at Very Cold and Ultra Cold neutrons

The main cold source in HighNESS is intended to serve instruments, and secondary VCN and UCN sources

The number and configuration of sources to deliver VCN and UCN is the focus of this workshop.

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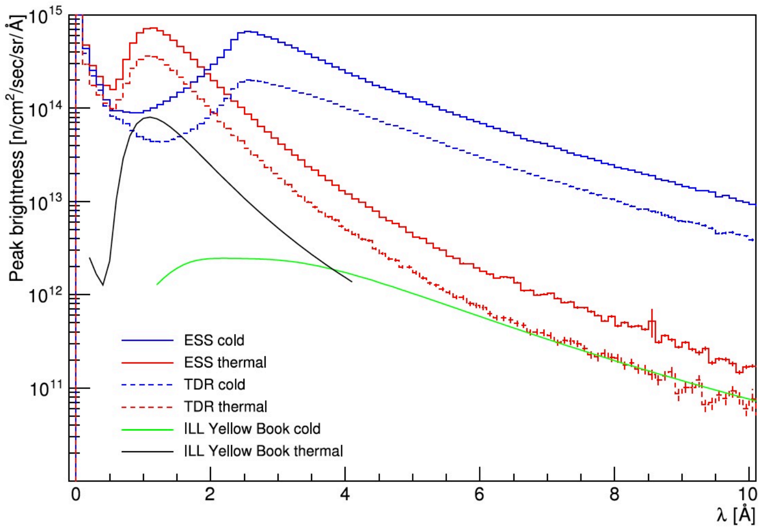
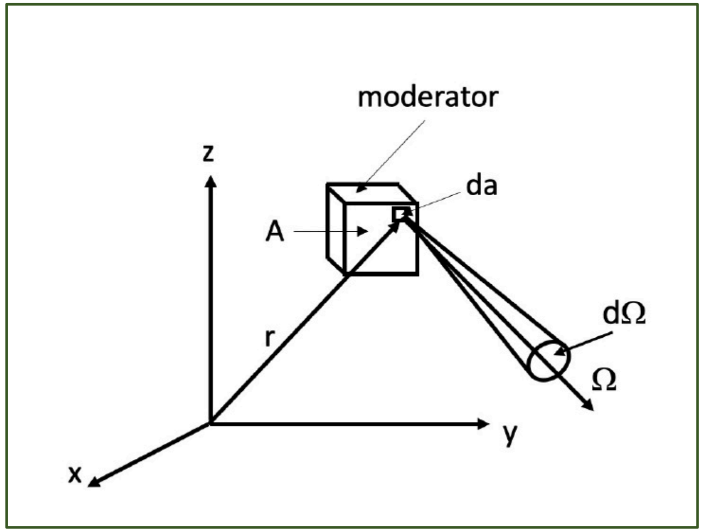
Brightness

- Angular flux emitted from moderator, averaged over moderator surface
- Constant along particle trajectory in conservative force fields (Liouville's theorem)
- ESS upper moderator designed optimizing brightness and brightness transport to the sample
- ESS reference suite: K.H. Andersen, D.N. Argyriou, A.J. Jackson et al., The instrument suite of the European Spallation Source, Nuclear Inst. and Methods in Physics Research, A (2020), doi: https://doi.org/10.1016/j.nima.2020.163402.

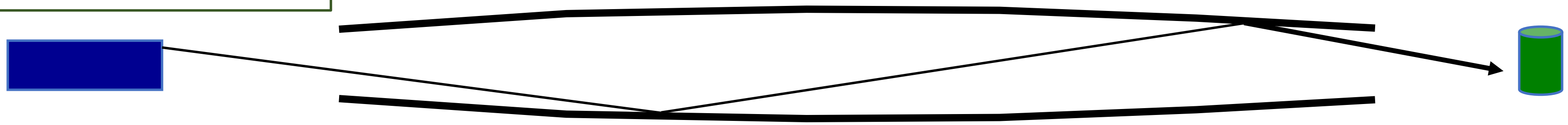


L. Zanini et al. Nuclear Inst. and Methods in Physics Research, A 925 (2019) 33–52



$$\phi(r, \Omega, E, t) = v \cdot N(r, \Omega, E, t), \quad [\text{n/cm}^2\text{/s/sr/eV}]$$

Beam requirements:
- Area
- Divergence
- Wavelength



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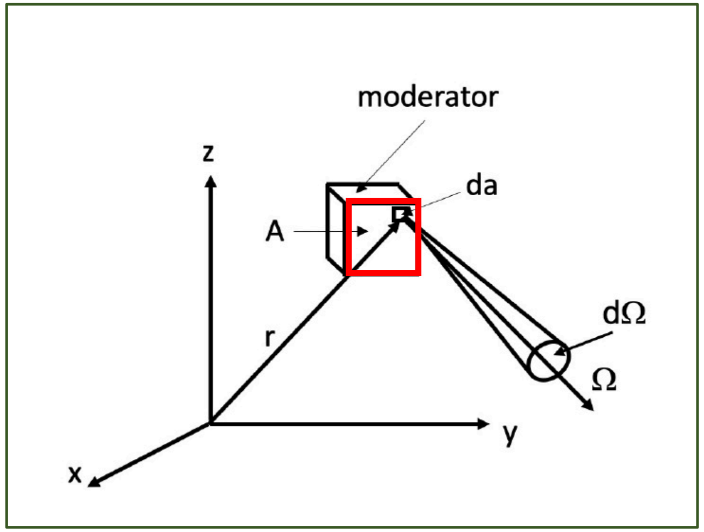
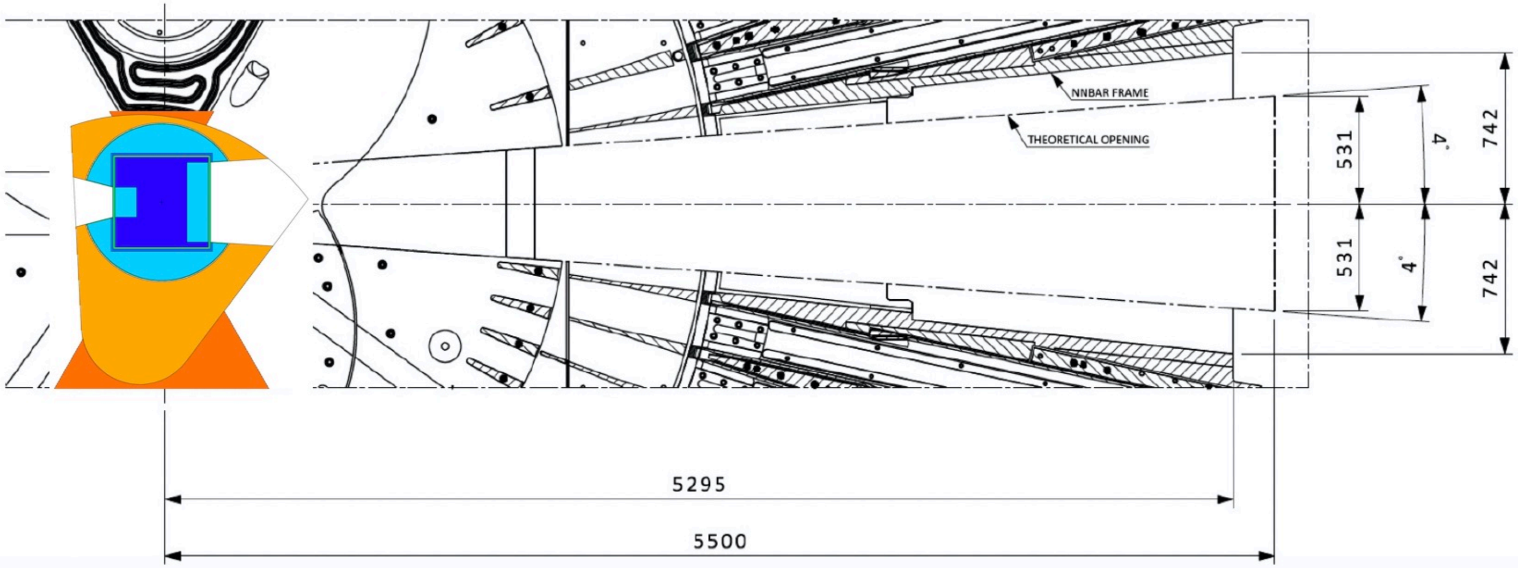
Intensity

HighNess

- Brightness integrated over the moderator surface
- Focus more on total number of neutrons than on divergence.
- Example: NNBAR



$$I_N(E, \Omega, t) = \int_A da \cdot \ v \cdot N(r, \Omega, E, t). \quad \text{[n/s/sr/eV]},$$



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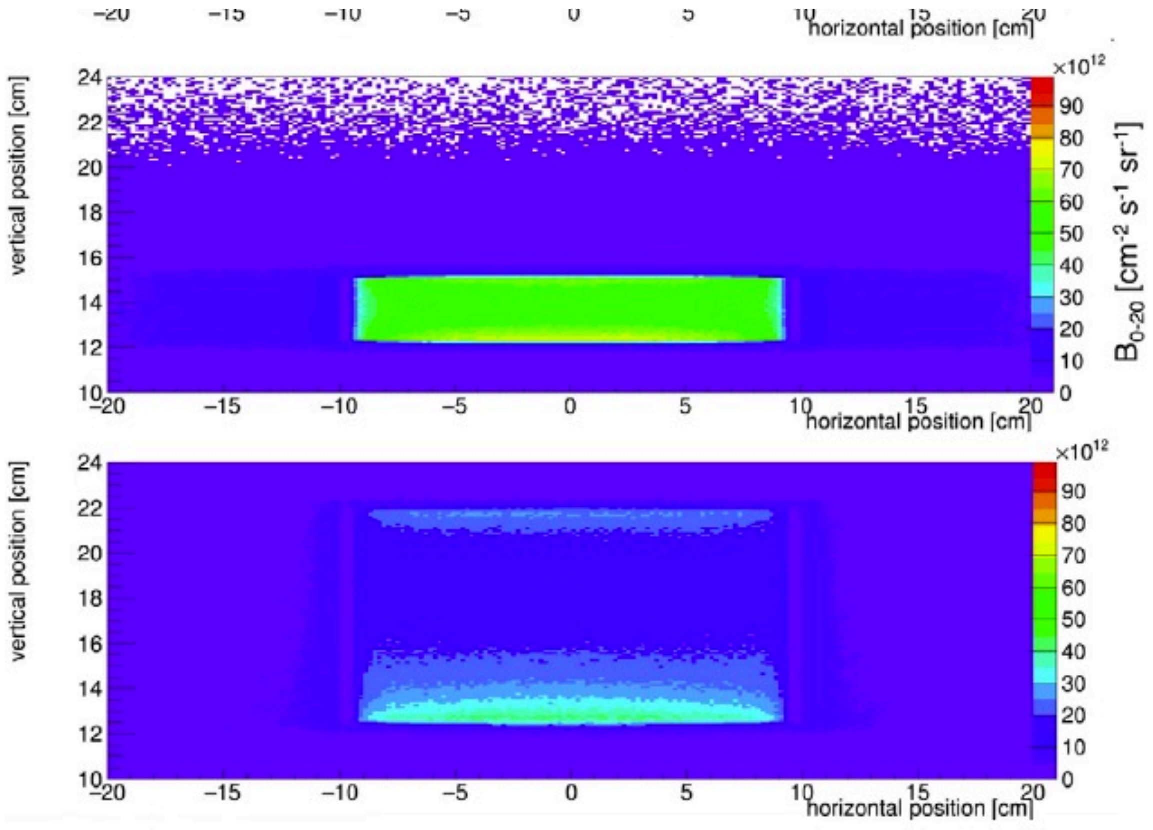
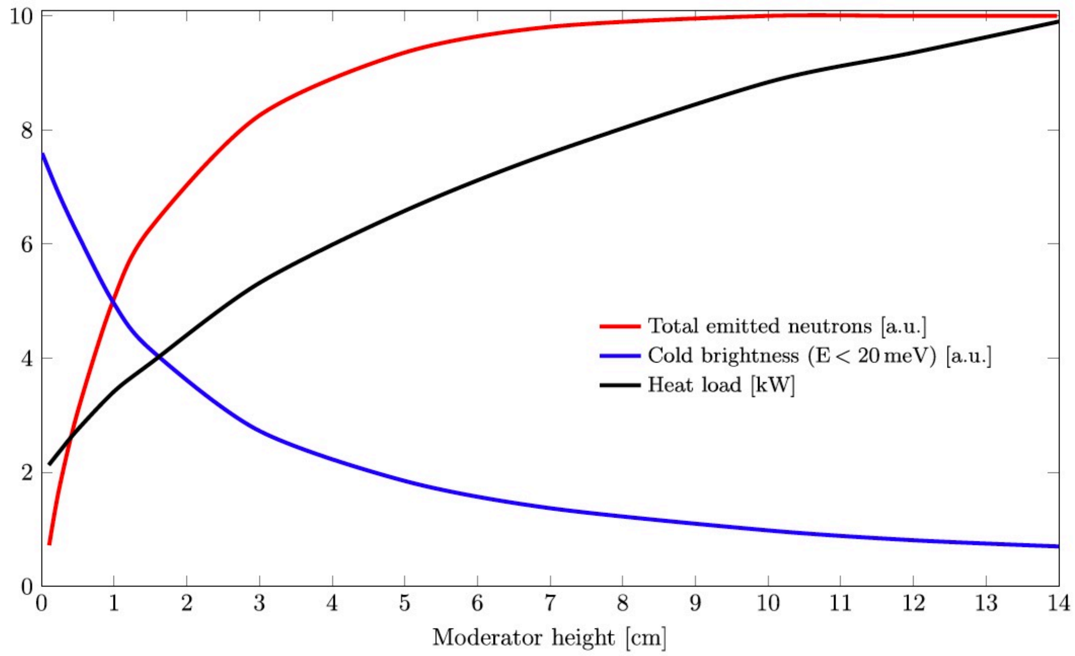
We cannot reach high intensity with parahydrogen





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

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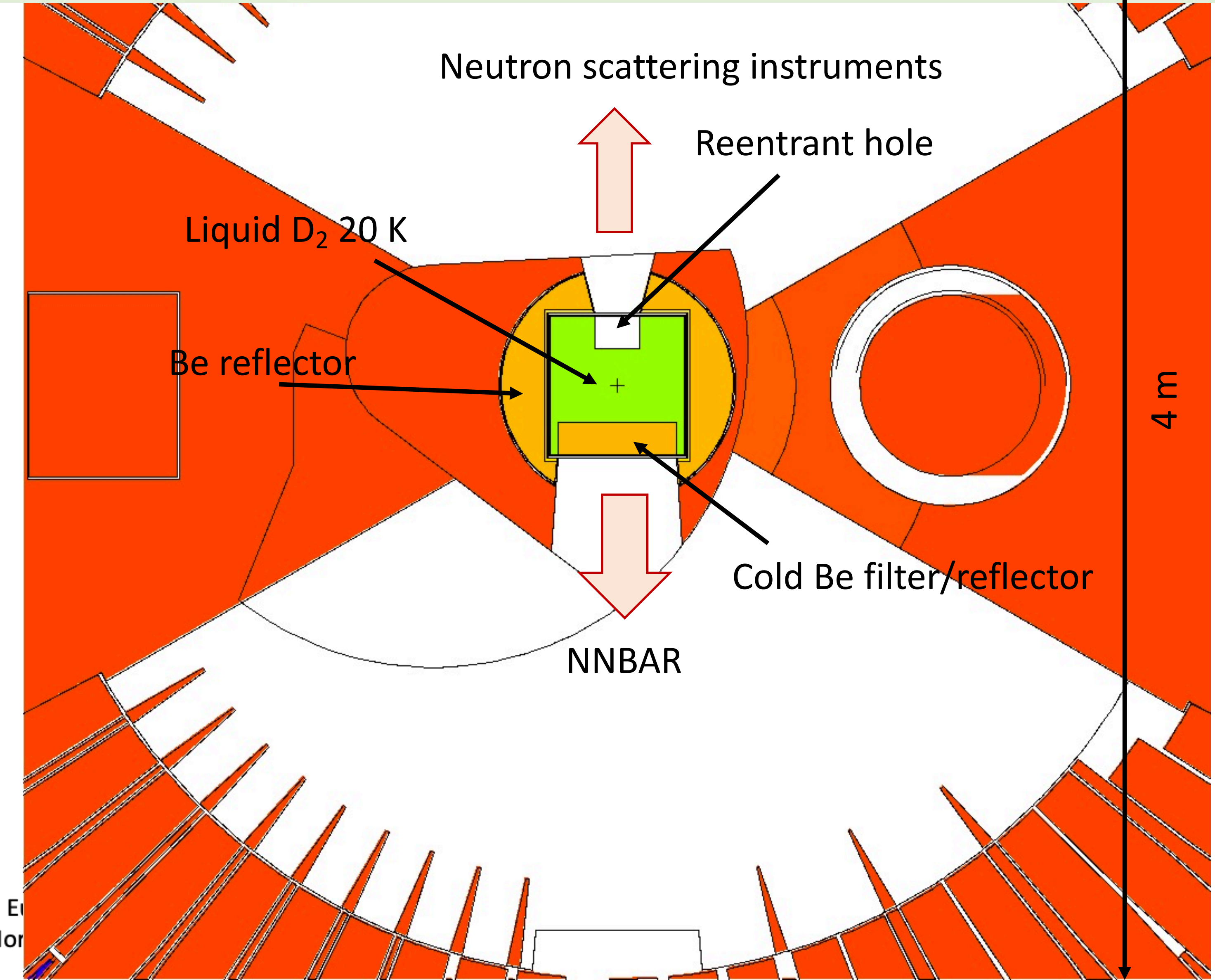
Baseline design and performance of the liquid deuterium moderator



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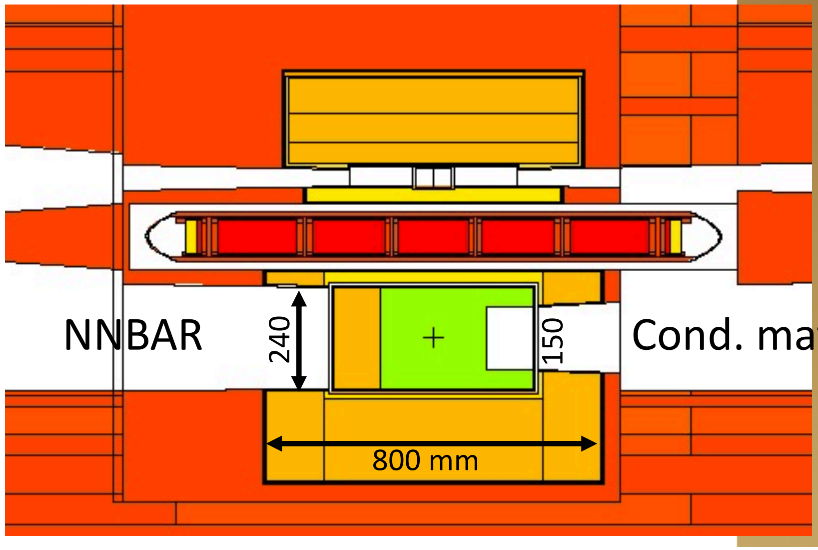
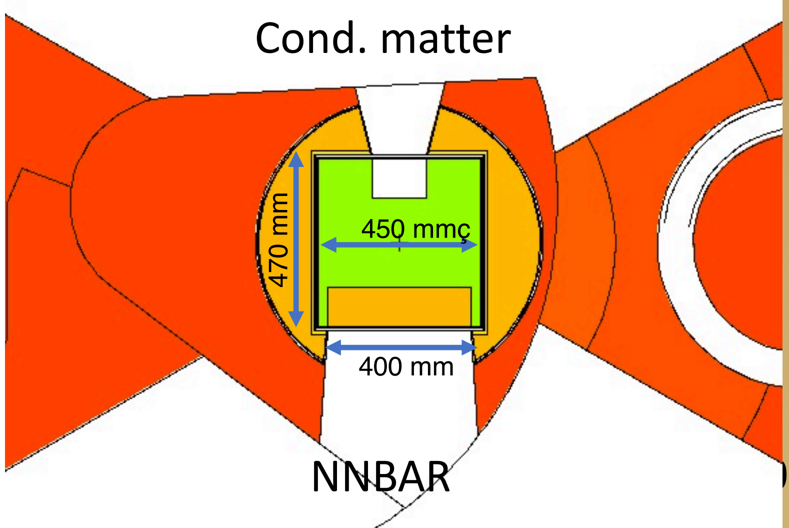
Comparison lower moderator (2 openings) upper moderator, integral values for CN and VCN (> 10 Å), brightness and intensity

Moderator surface	BRIGHTNESS [n/cm2/s/sr]	> 2 Å	> 4 A	> 10 Å
24 × 40 cm^2	NNBAR	9.0E+12	7.2E+12	5.7E+11
15 × 15 cm^2	WP7	1.8E+13	1.1E+13	9.5E+11
3 × 7 (×2) cm^2	upper mod	5.3E+13	1.7E+13	9.9E+11
	INTENSITY [n/s/sr]			
24 × 40 cm^2	NNBAR	8.7E+15	6.9E+15	5.4E+14
15 × 15 cm^2	WP7	4.1E+15	2.5E+15	2.1E+14
3 × 7 (×2) cm^2	upper mod	2.2E+15	7.0E+14	4.2E+13





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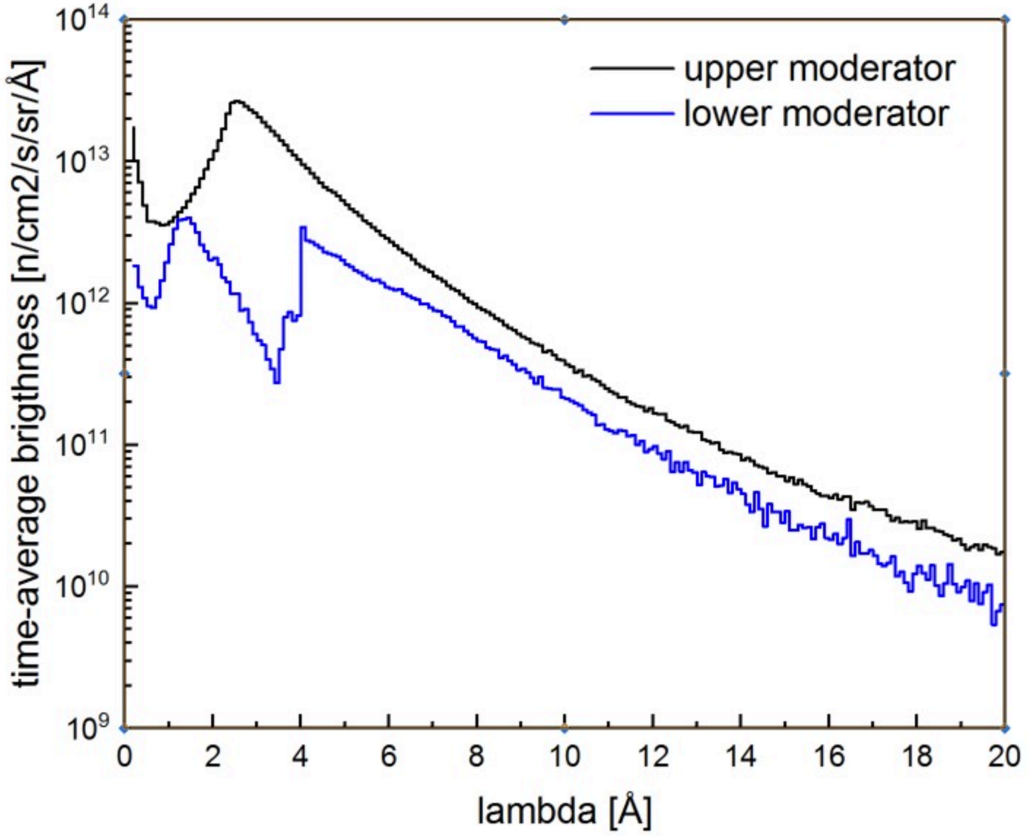
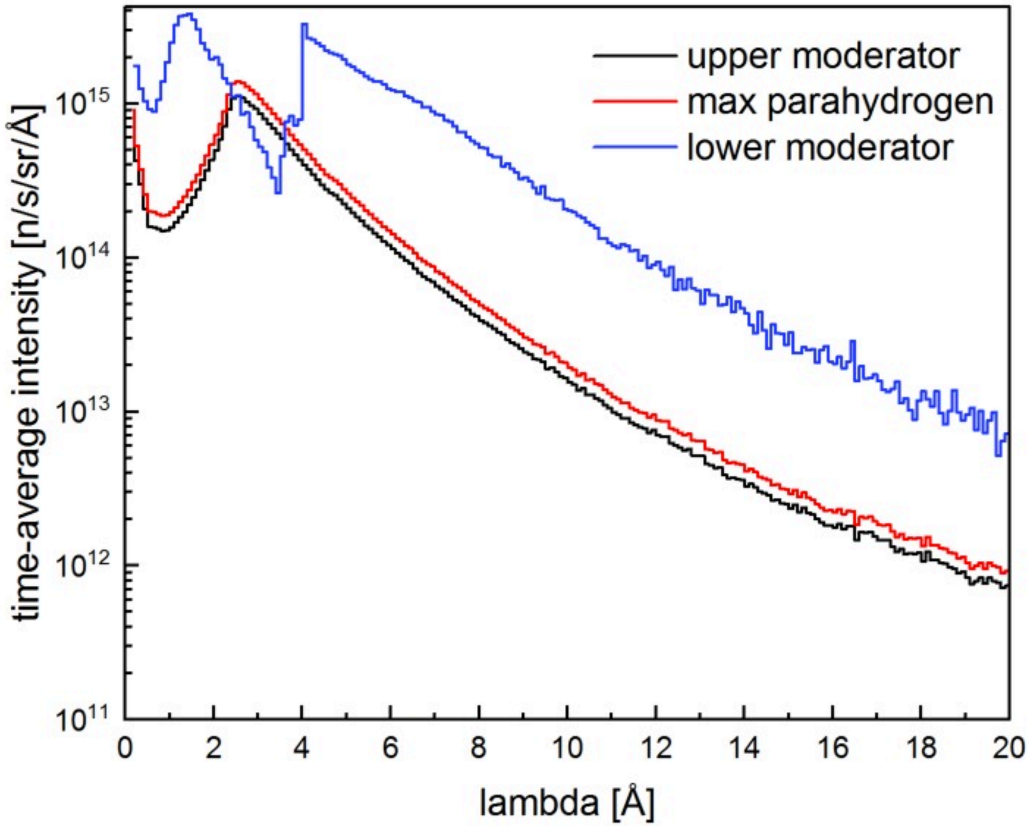
Brightness and intensity comparison, upper and lower moderators

brightness



intensity



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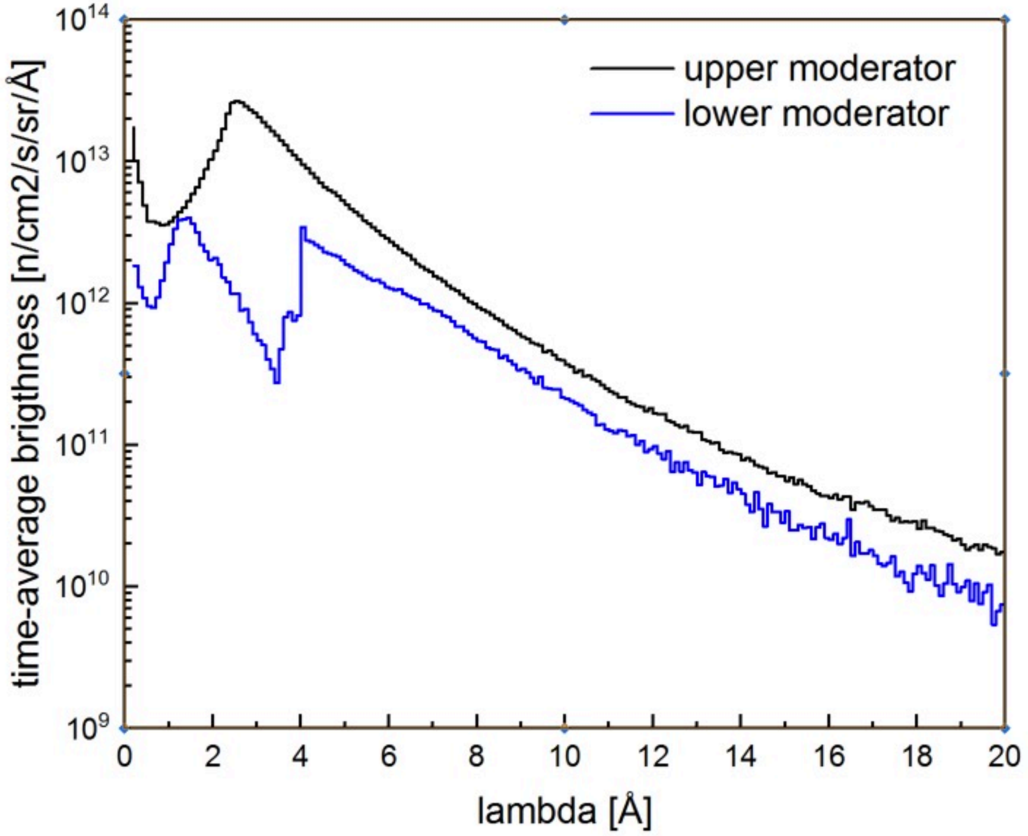
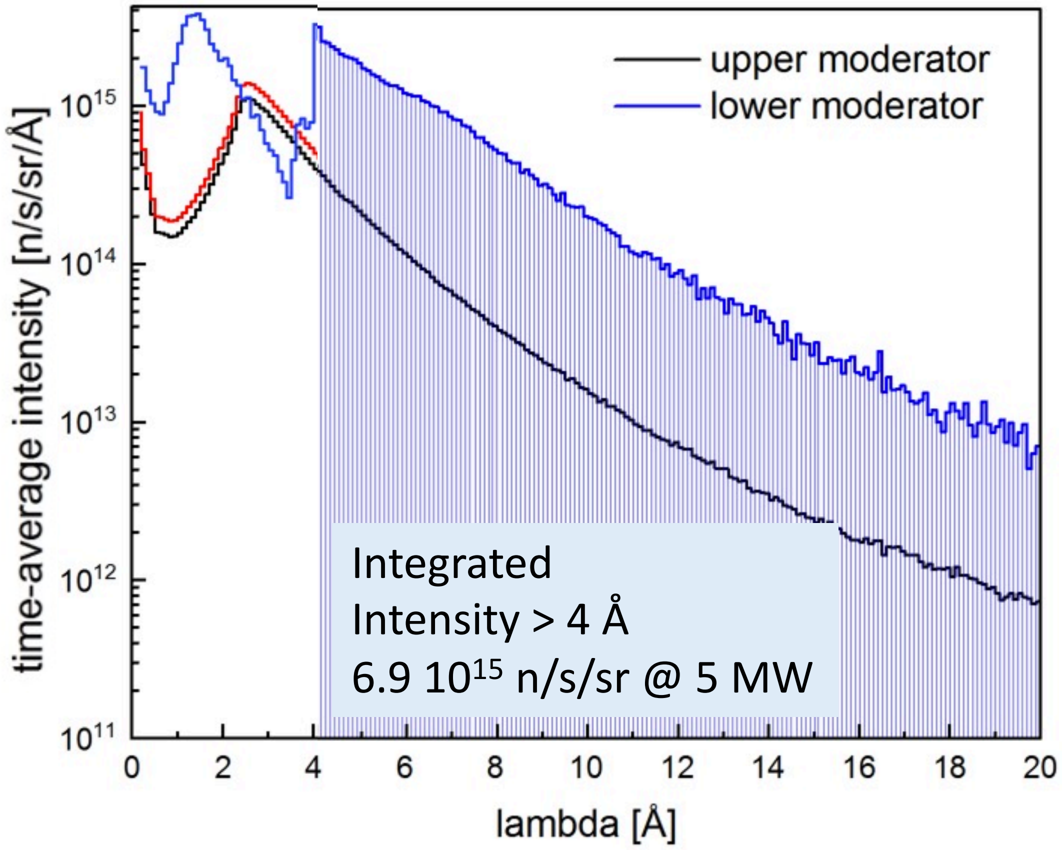
Brightness and intensity comparison, upper and lower moderators

brightness



intensity



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Brightness, of interest for UCN, and heat loads at 5 MW

Cold time average brightness lower moderator, NNBAR side, integrated below 10 meV, viewed surface 24X40 cm^2	7.8 10^{12} $n/cm^2/s/sr$
Cold time average brightness lower moderator, cond. matter side, integrated below 10 meV, viewed surface 15X15 cm^2	1.5 10^{13} $n/cm^2/s/sr$
8.9 Å time average brightness lower moderator, NNBAR side, viewed surface 24X40 cm^2	3.4 10^{11} $n/cm^2/s/sr/Å$
Upper moderator, liquid parahydrogen and Al vessel cryogenic parts	7 KW
Lower D2 moderator, liquid D2 and Al vessel cryogenic parts	57 KW

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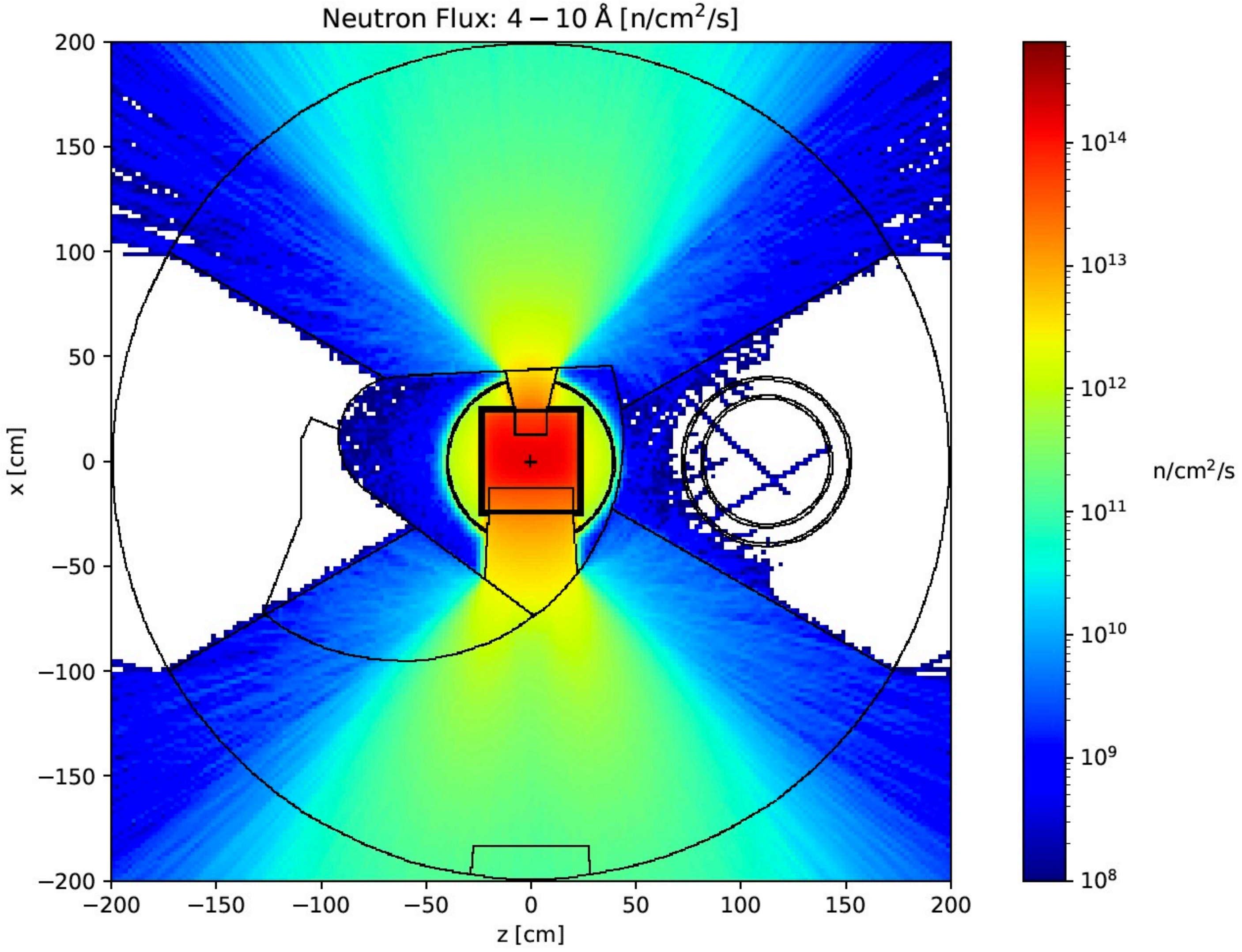
Maps of cold neutrons @ 5 MW



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- First, we show general drawings of the ESS monolith,
- then the possible locations so far identified for VCN and UCN sources
- More detailed presentation of ESS monolith by U. Odén

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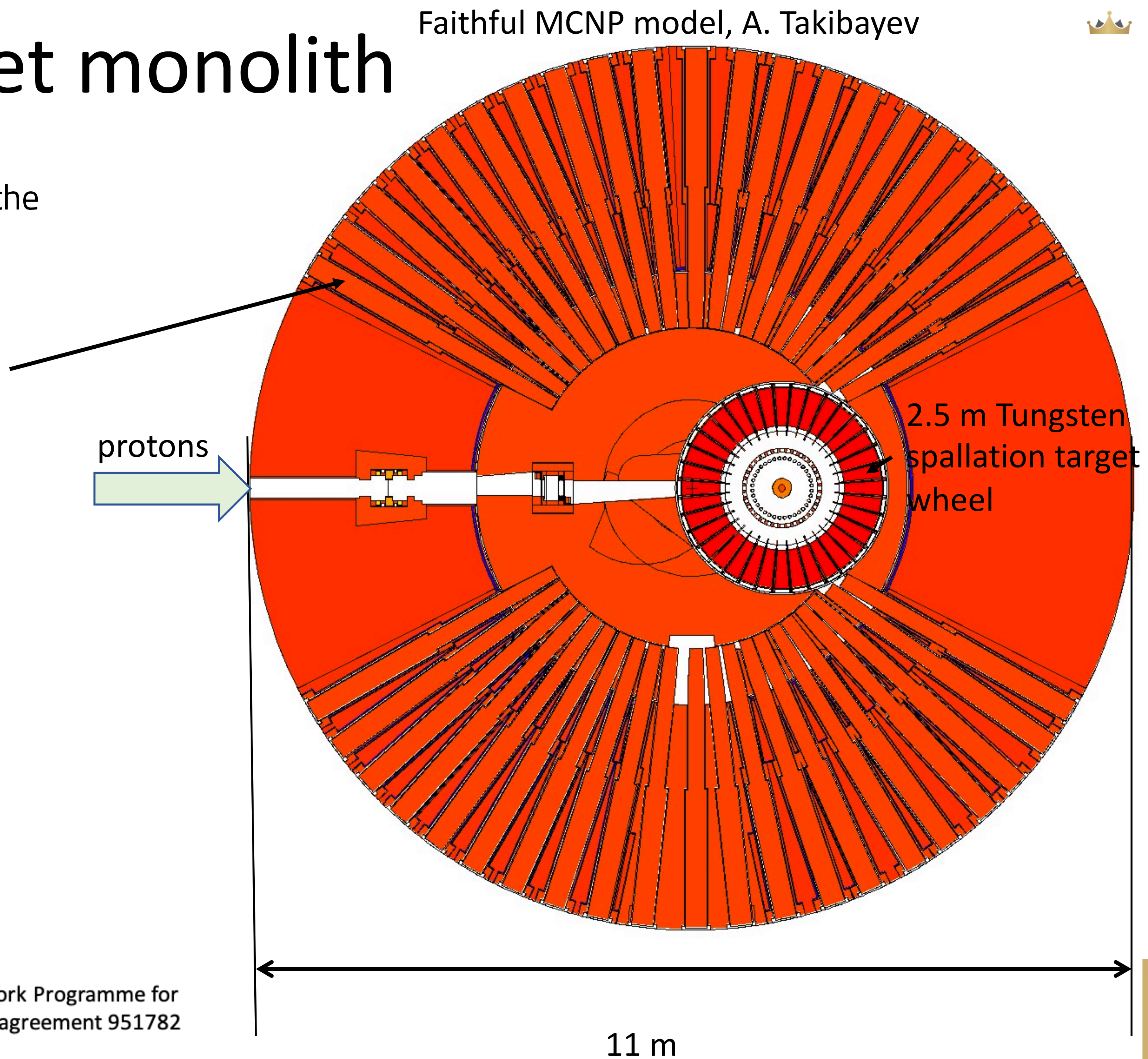
VIew of the target monolith

- View of the ESS target monolith at the level of the tungsten target, Z=0
- 42 Plugged neutron beamports for instrument placement.
- 15 instruments will be built at the start of ESS (beamports will contain neutron guides)
- Dimensions of the steel plugs:
  - 3.5 m long,
  - height about 62 cm,
  - width at the tip about 16 cm.



DRAWING-1

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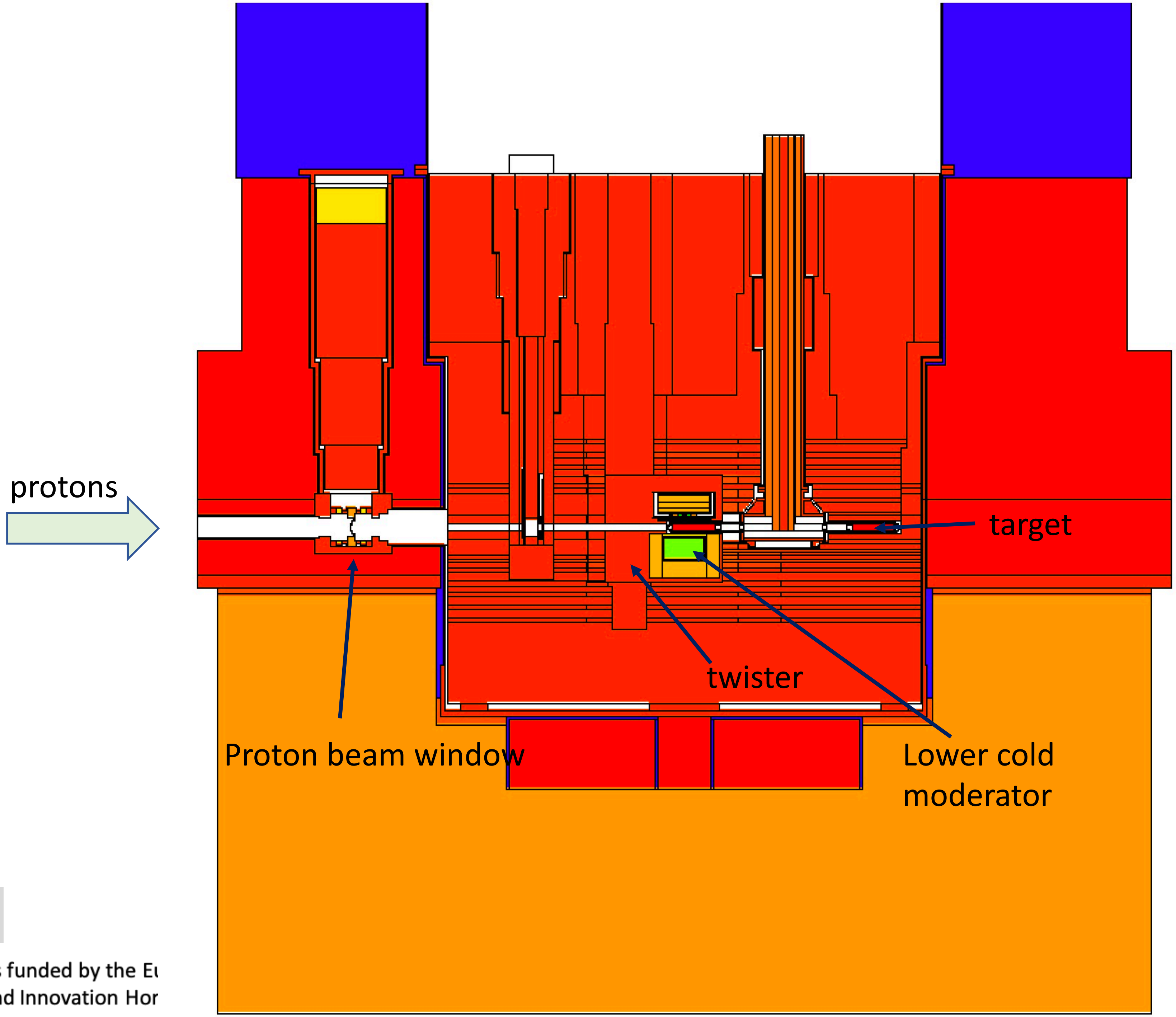

DRAWING-2

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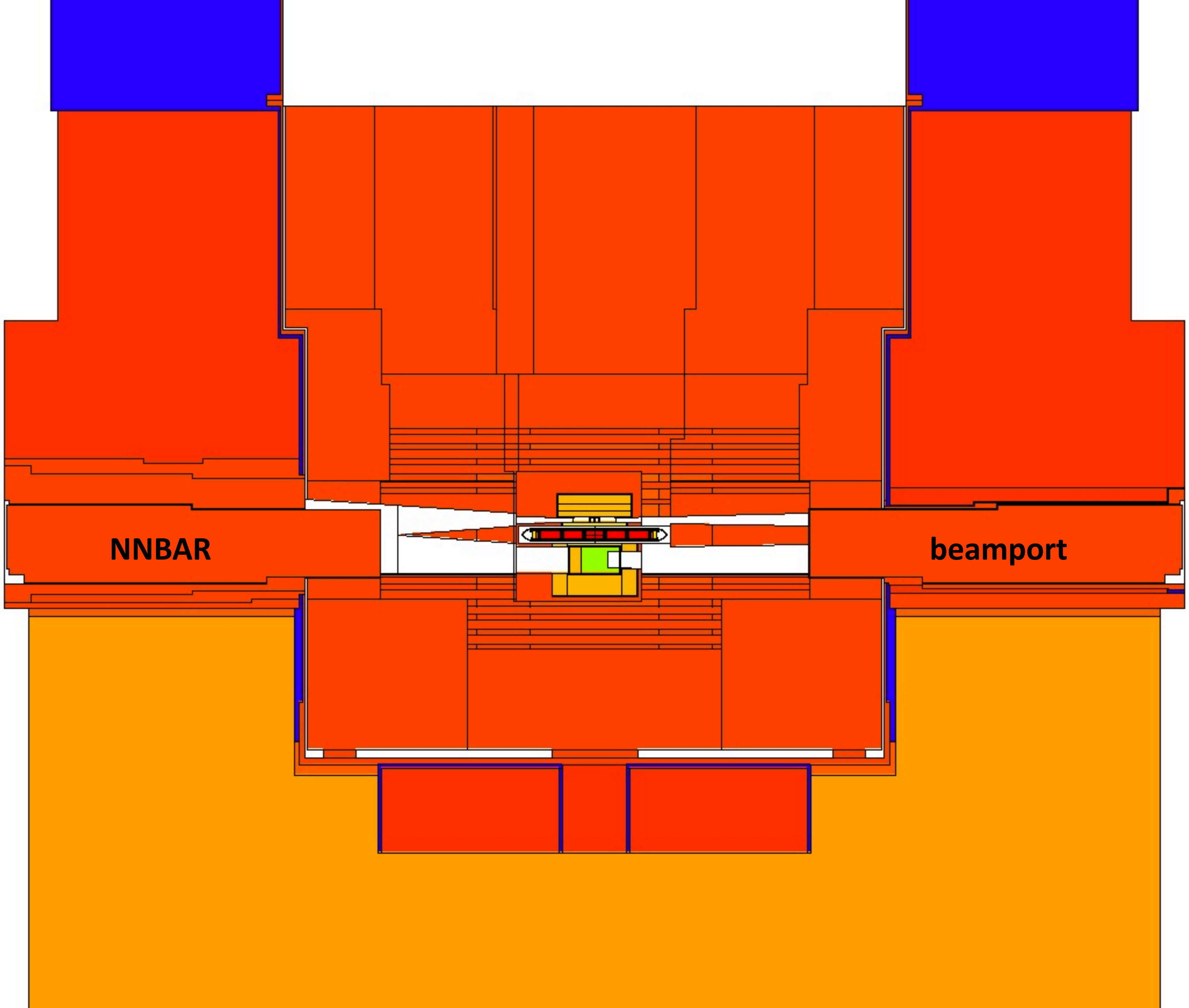

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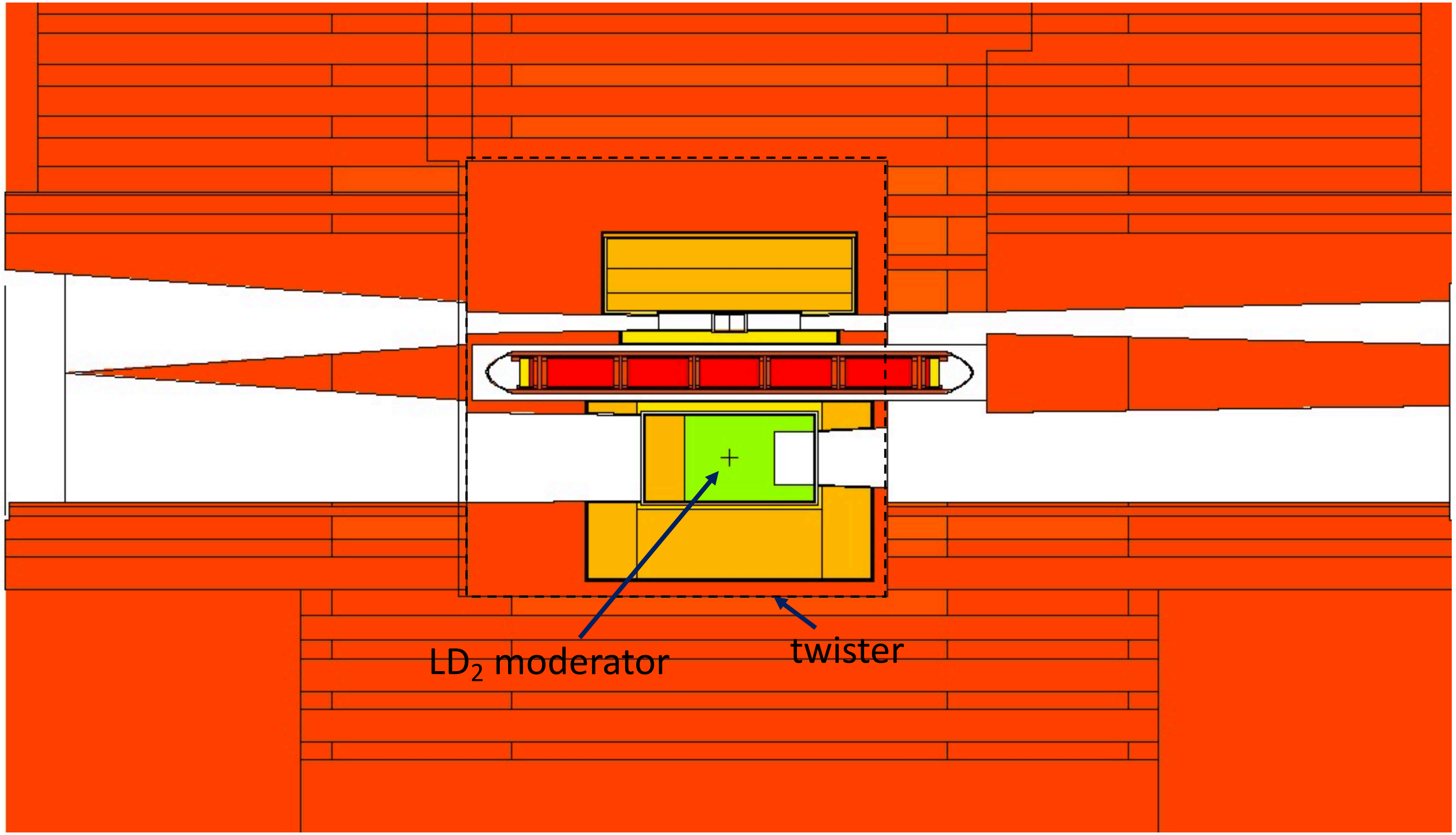

DRAWING-4

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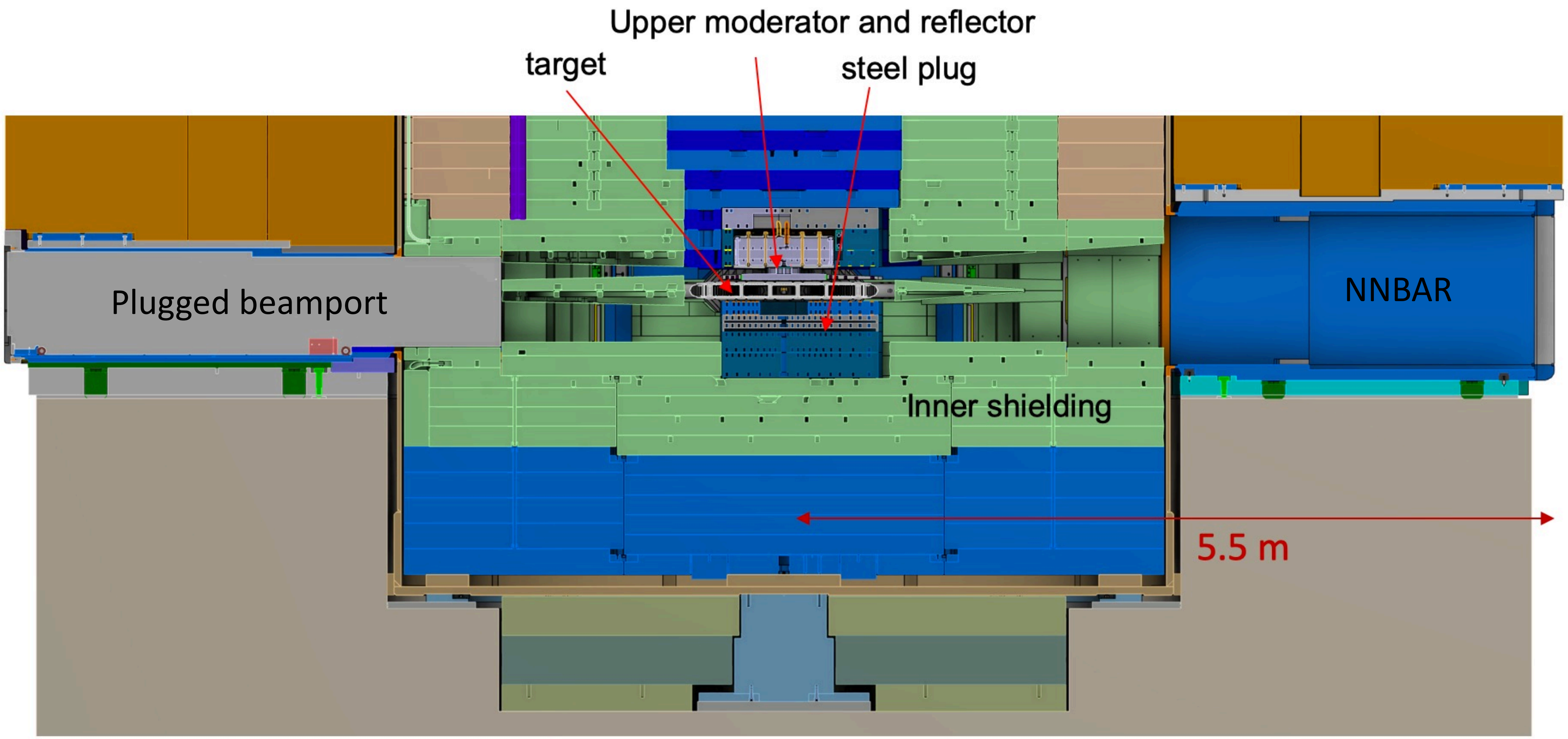

DRAWING-5

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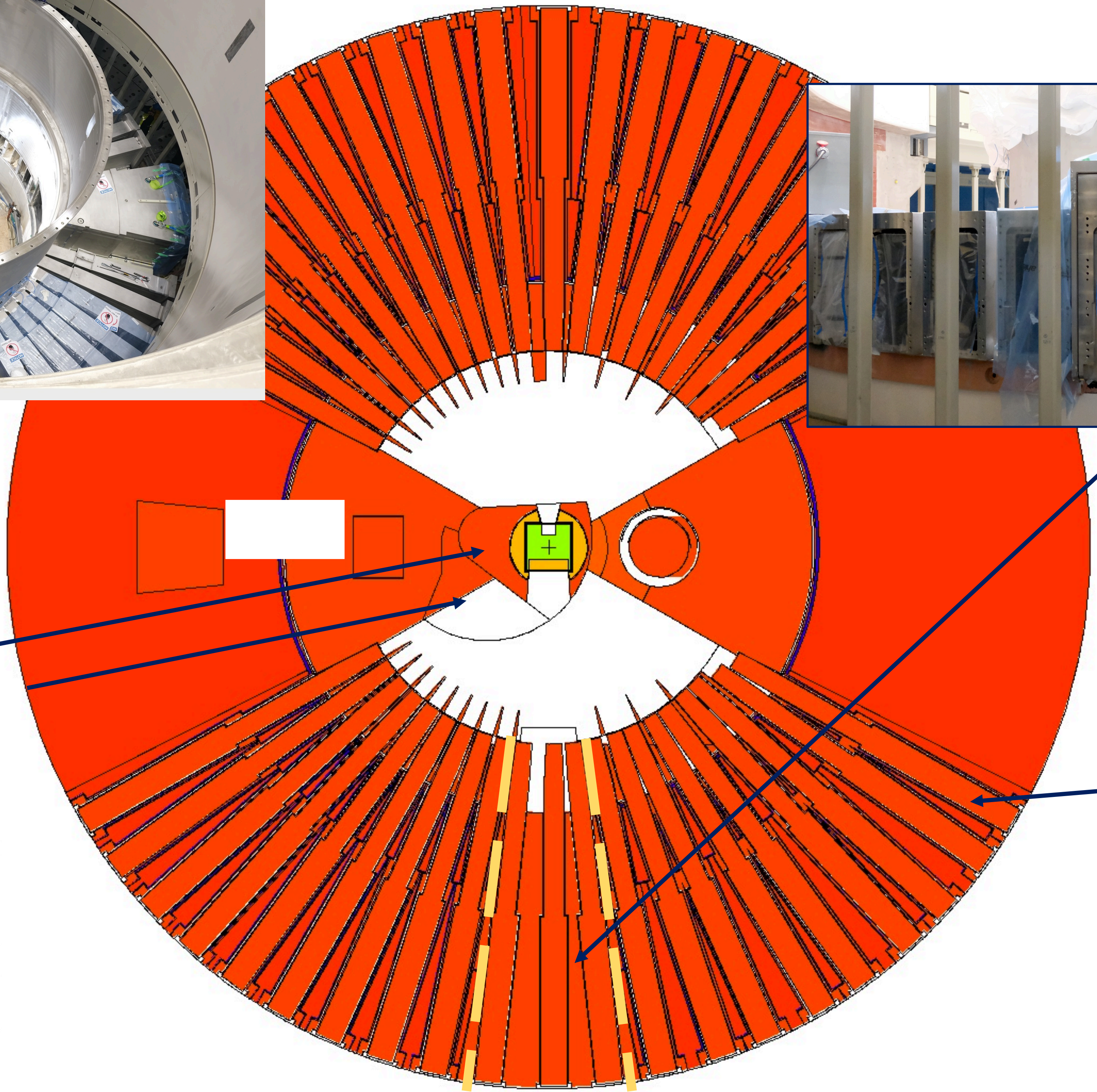


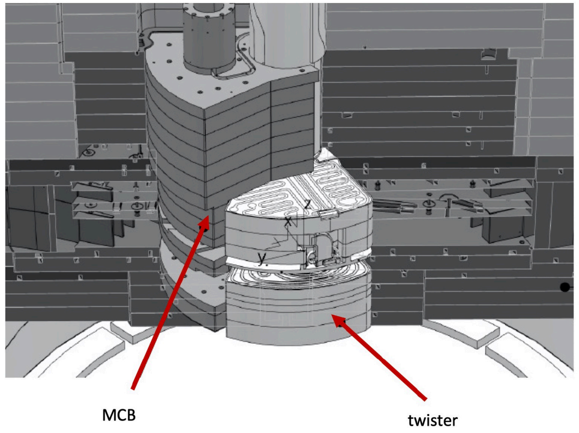
protons

twister

Moderator Cooling Block

Large beamport

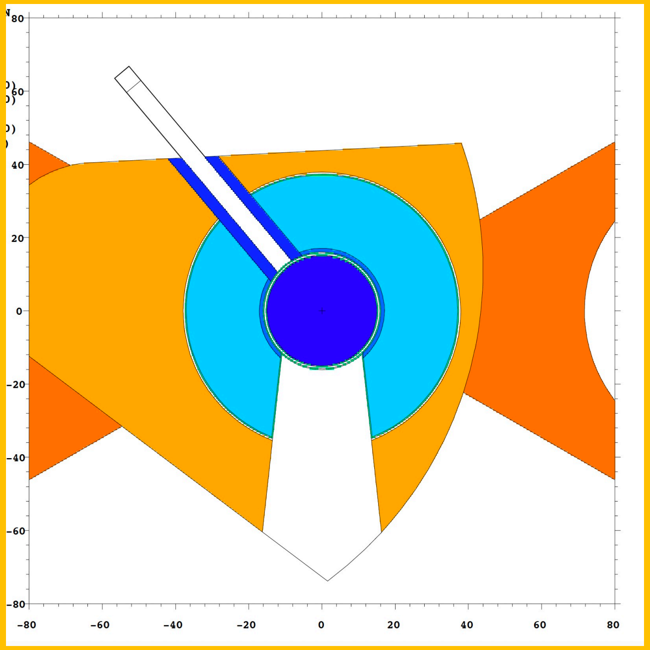
Regular beamport



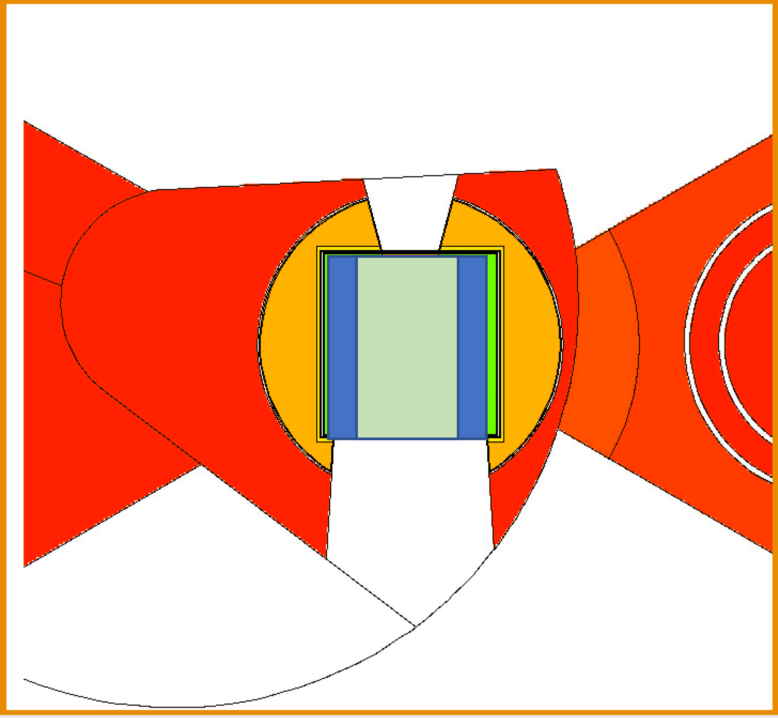
DRAWING-6

The two VCN options

VCN extraction from cold source



VCN dedicated converter



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First VCN option: extraction of VCN from LD2 source

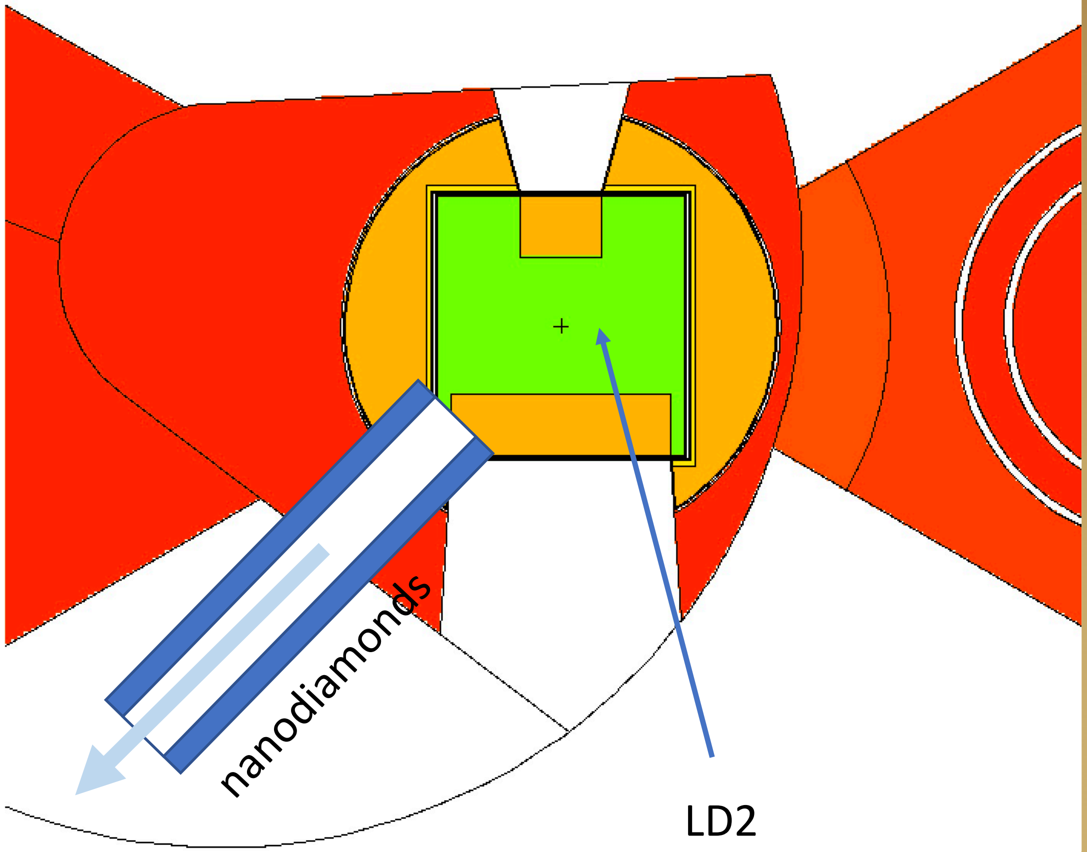
- Location of the source: attached to main LD2 moderator
- Insert a channel from the main liquid D2 cold source and extract CN and VCN by using advanced reflectors(e.g. nanodiamonds)
- This is the main solution within HighNESS
- A prototype of advanced reflector will be tested at the Budapest Research Center (see A. Szakal presentation)

PROS:

- Close to source: high brightness

CONS

- Limited to the VCN you get from the cold source
  (Maxwellian tail from 20 K spectrum)
- Small extraction channel (e.g. 3X3 cm^2) to have sizeable effect from reflector



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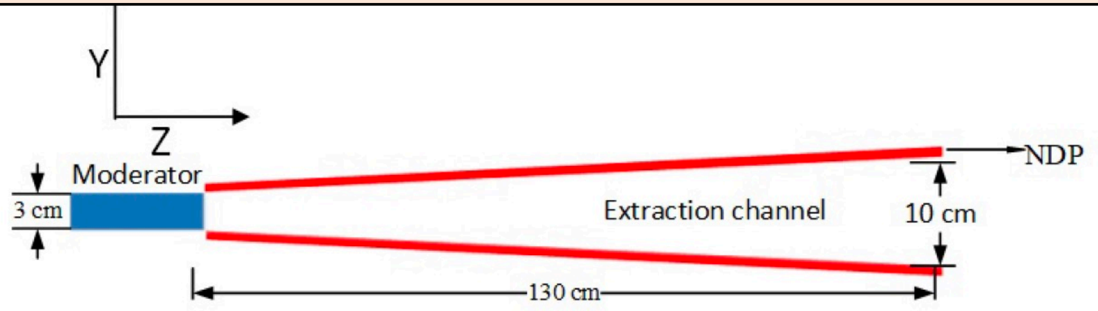
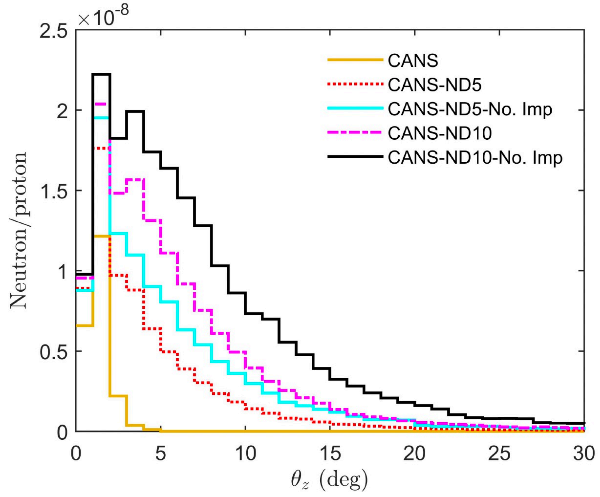
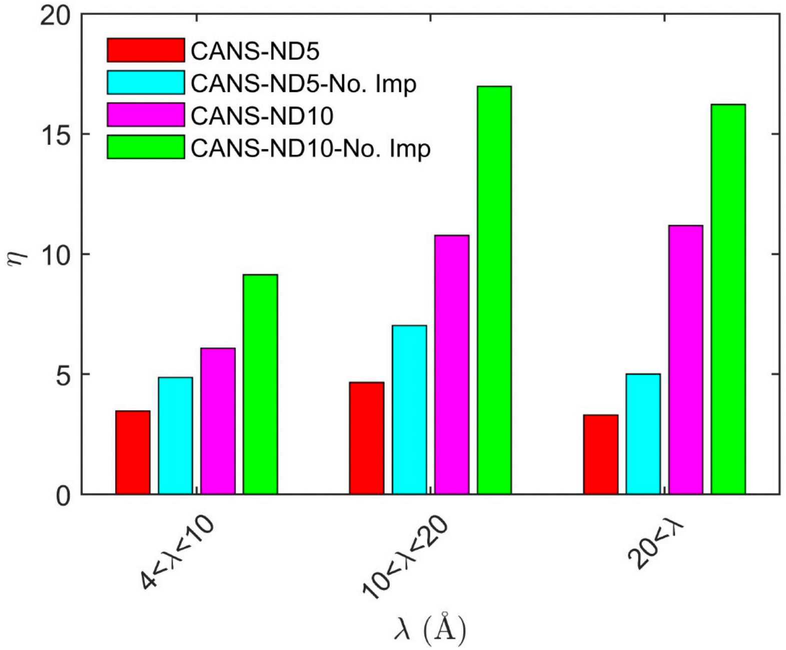
First option: an example of what we hope to achieve

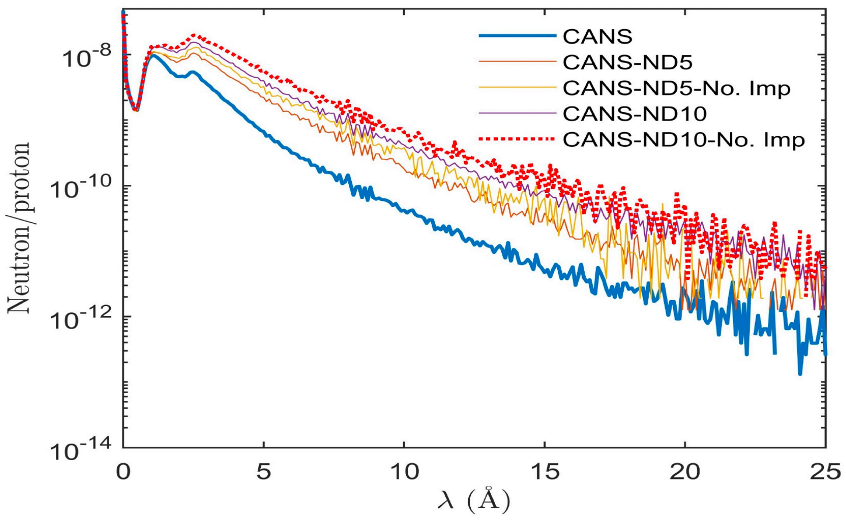
HighNess

M. Jamalipour et al, Improved beam extraction at compact neutron sources using diamonds nanoparticles and supermirrors, PhD thesis; paper submitted for publication









Second VCN option: dedicated source

- Use a dedicated VCN converter, e.g. solid D2 at 5 K, or deuterated clathrate hydrates at around 2 K.
- Might use also reflectors such as nanodiamonds or MgH2 e.g. to compensate for long mean free path of CN in solid D2.

Possible **locations**: if high flux is needed:

- twister (but might have to replace the main source)
- Moderator Cooling Block.

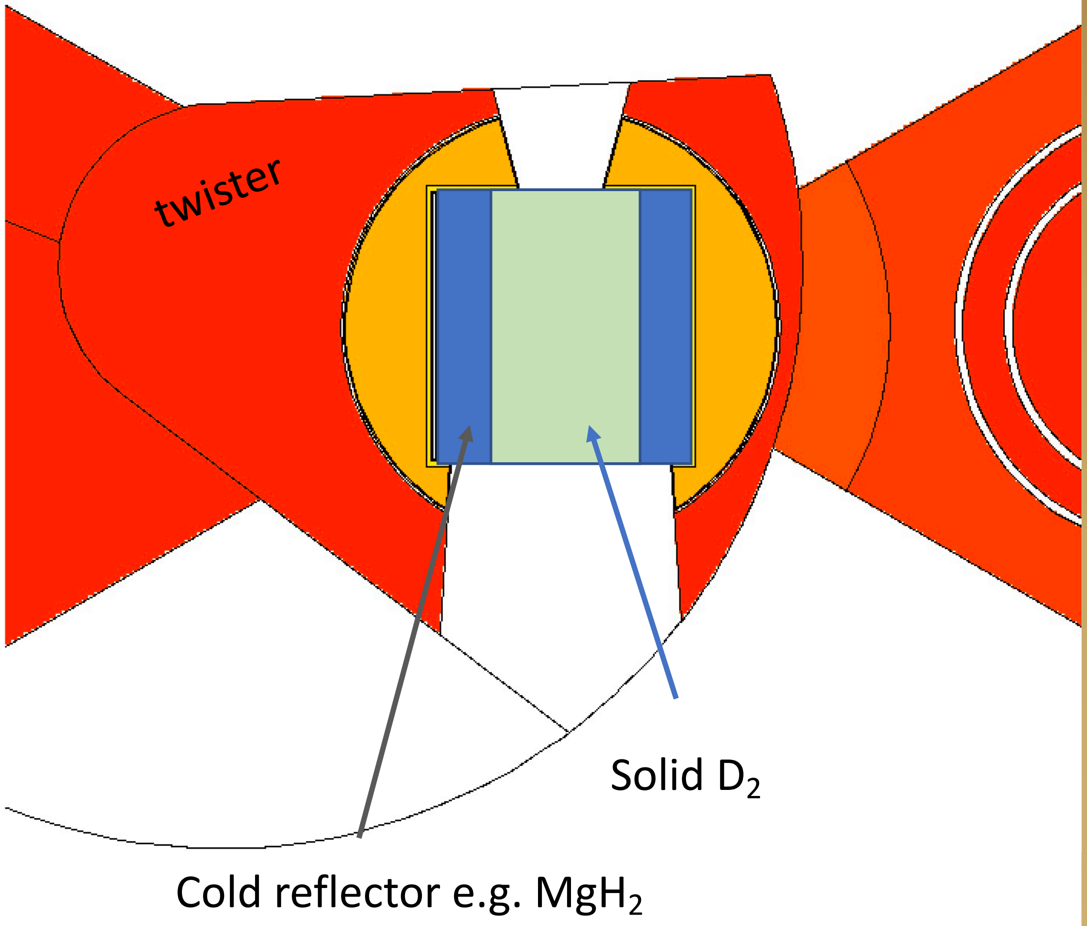
- If no high flux needed, such a source can be placed farther away.

PROS

- colder spectrum, more VCNs from the source
- High intensity (larger emission surface)

CONS

- Cooling, if too close to target



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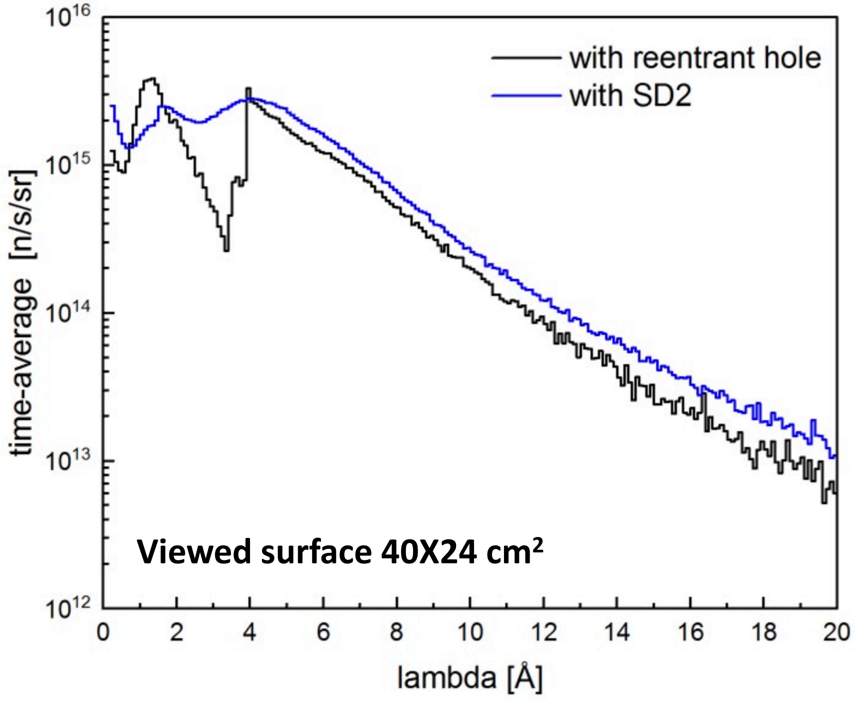
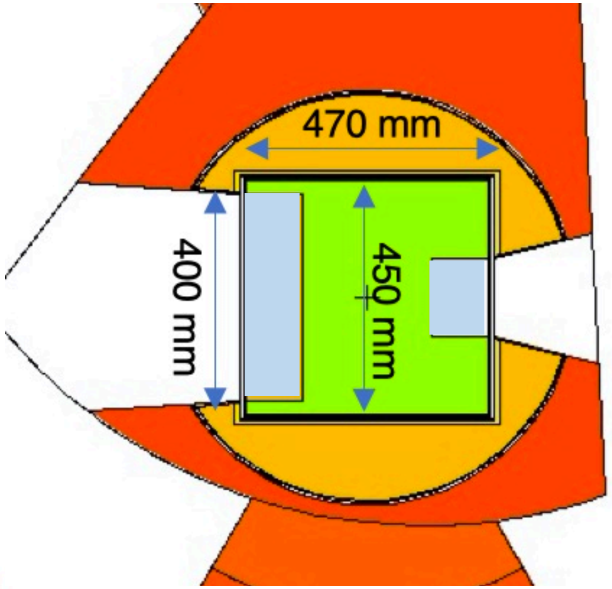
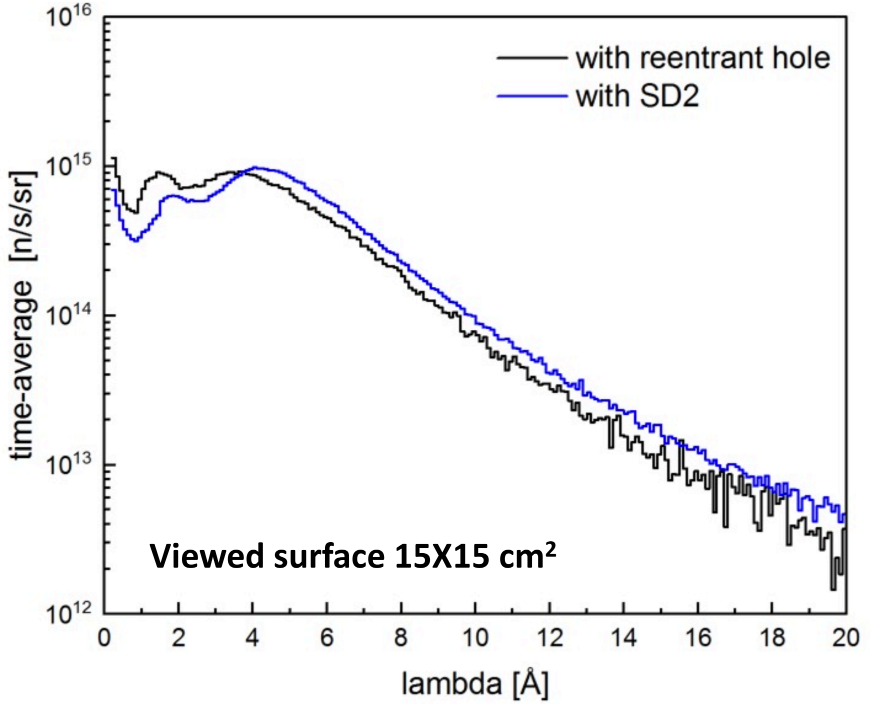
Second VCN option: spectral shift using solid deuterium

In this test, soild deuterium is replacing both the Be filter (13.7 cm) in the NNBAR side and the reentrant hole (12.7 cm) in the other side. Spectral shift is evident, but also a general gain.







Idea of V. Nesvizhevsky

To give an idea of heat loads: for this test: SD2 on NNBAR side: 7 kW; SD2 on cond. matter side: 1.7 kW

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Possible location of UCN sources

In pile

By in-pile, we mean inside the ESS monolith (R< 5.5 m)

4 different locations are possible inside the monolith, see next slides

See presentation of Ulf Oden for monolith description and engineering constraints.

Two materials identified, solid D2 and liquid He

Challenges:

Placement of the required equipment, e.g. cooling pipes

Cooling of the sources

Ackowledgments:
A. Serebrov

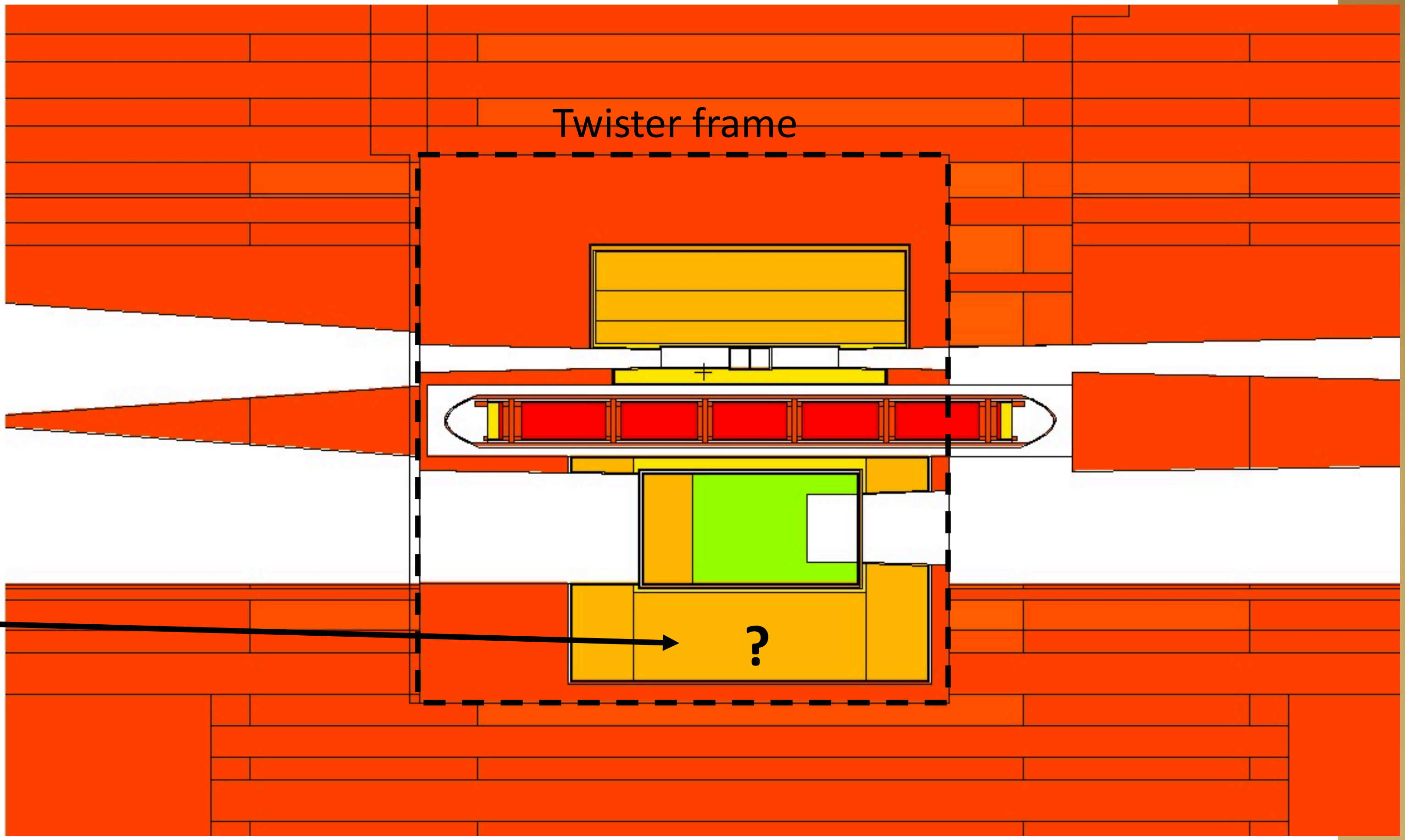
In beam

Location outside the monolith can start at 5.5 m (if inside ESS bunker or 15 m (if outside bunker).

Bunker is accessible only for maintenance or installation of new beamlines

1. UCN SOURCE IN THE TWISTER

CHALLENGES
Heat loads
Space taken by liquid D2 moderator
About 25 cm available in height, with current LD2 design
Extraction of neutrons



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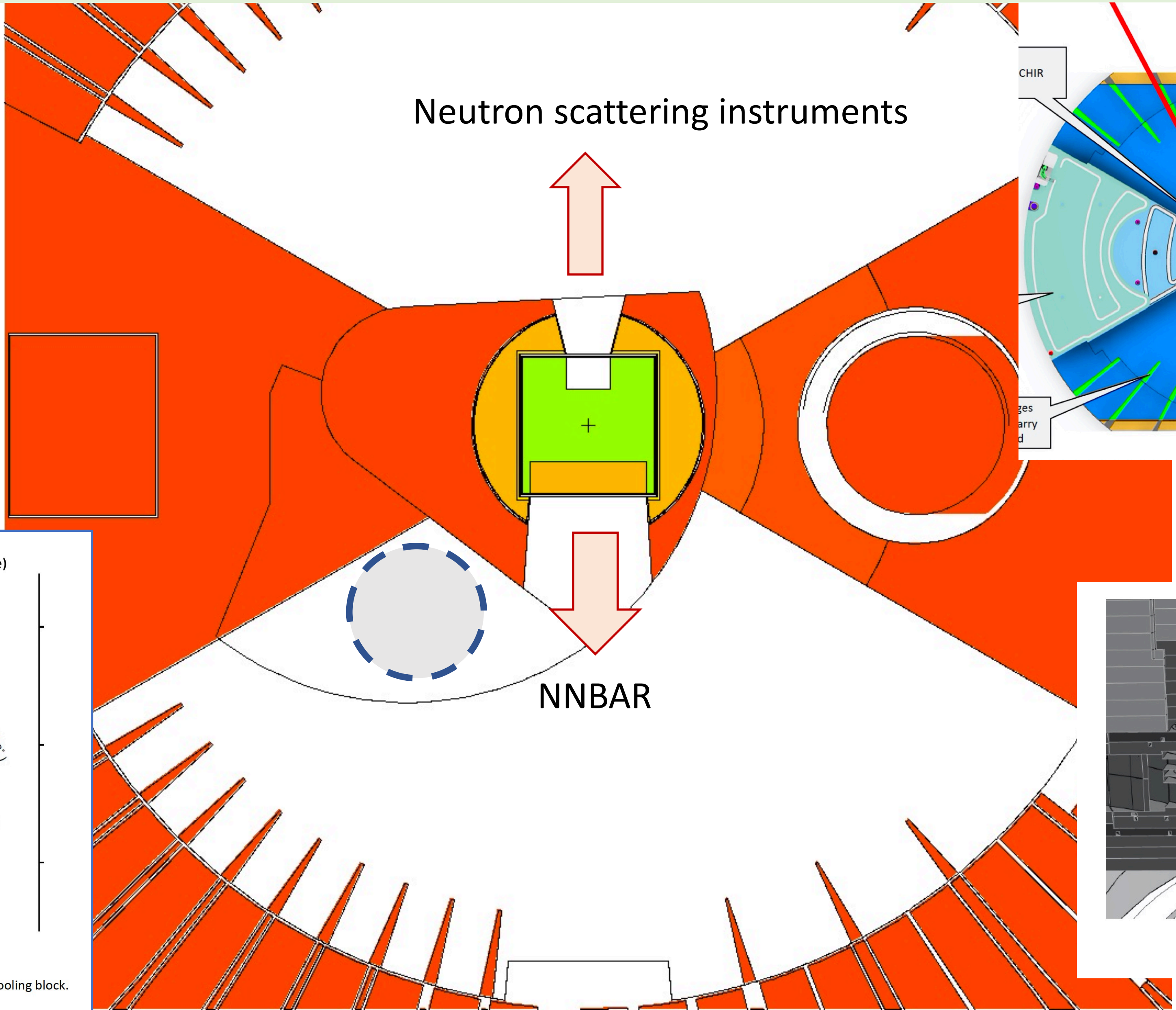
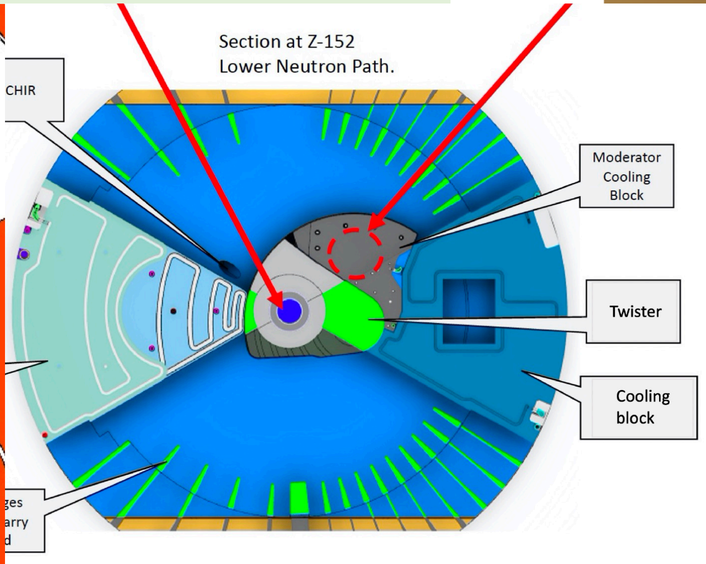
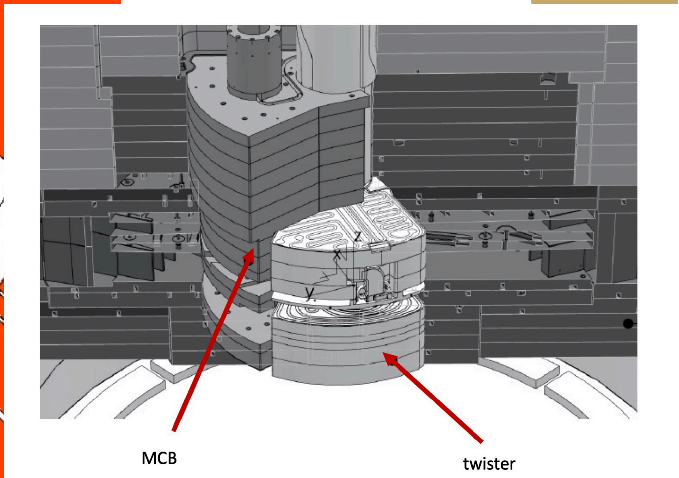
2. UCN source in Moderator Cooling Block (1)

2 options for insertion and cooling channels

- vertical access
- horizontal access (next slide)







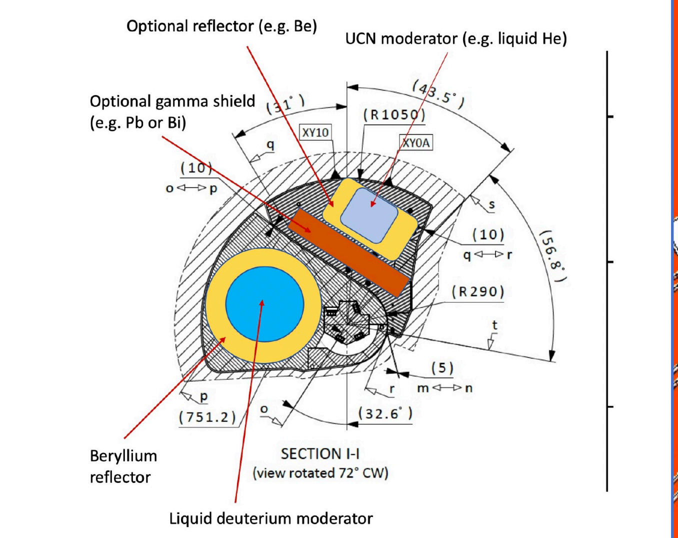
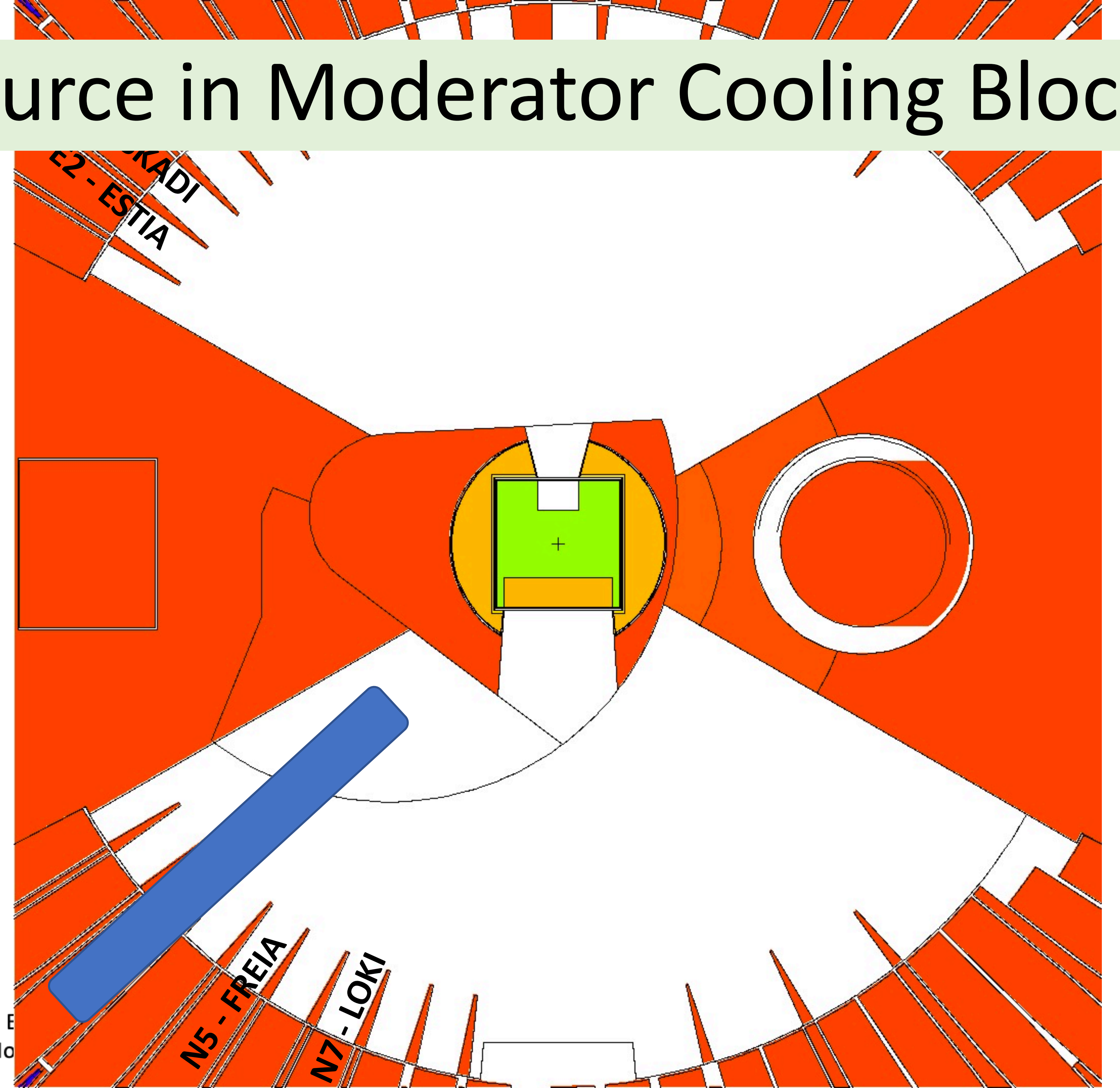


Figure 17: Possible location of an in-pile UCN source in the moderator cooling block.

2. UCN source in Moderator Cooling Block (2)

horizontal insertion of source (e.g. liquid He vessel) and necessary equipment



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3. UCN source in beamport (1)

A UCN source could occupy the tip (or all…) of one of the 42 beamports.

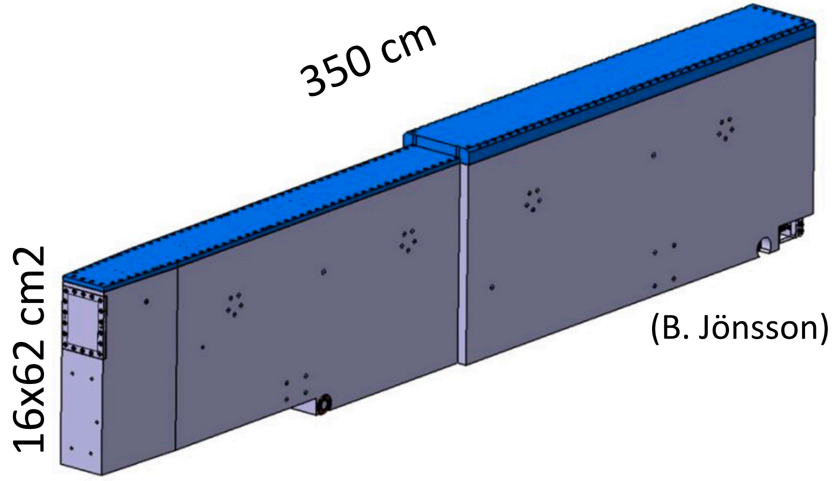
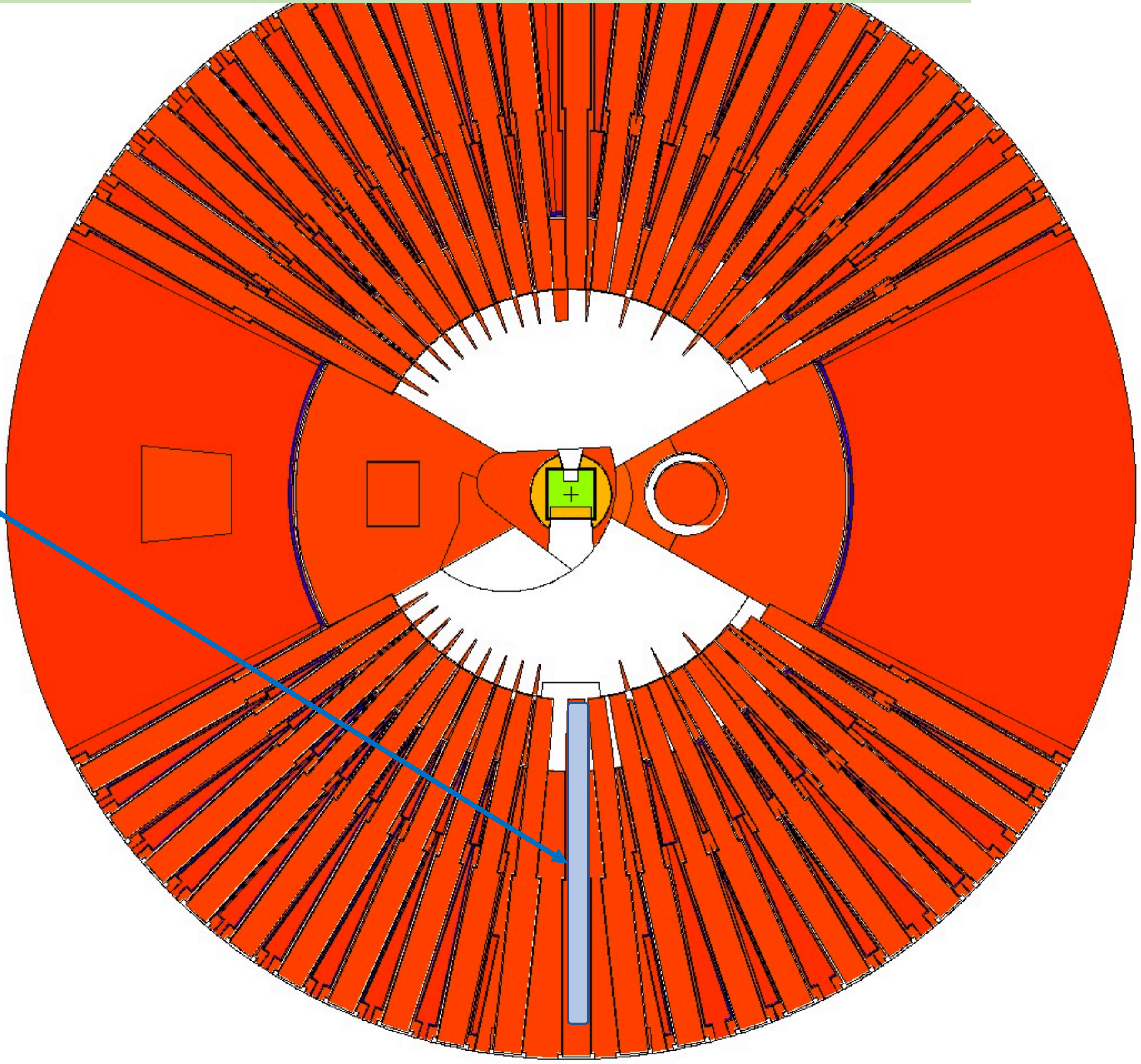


Figure 1: 3D model of the NBPI prototype



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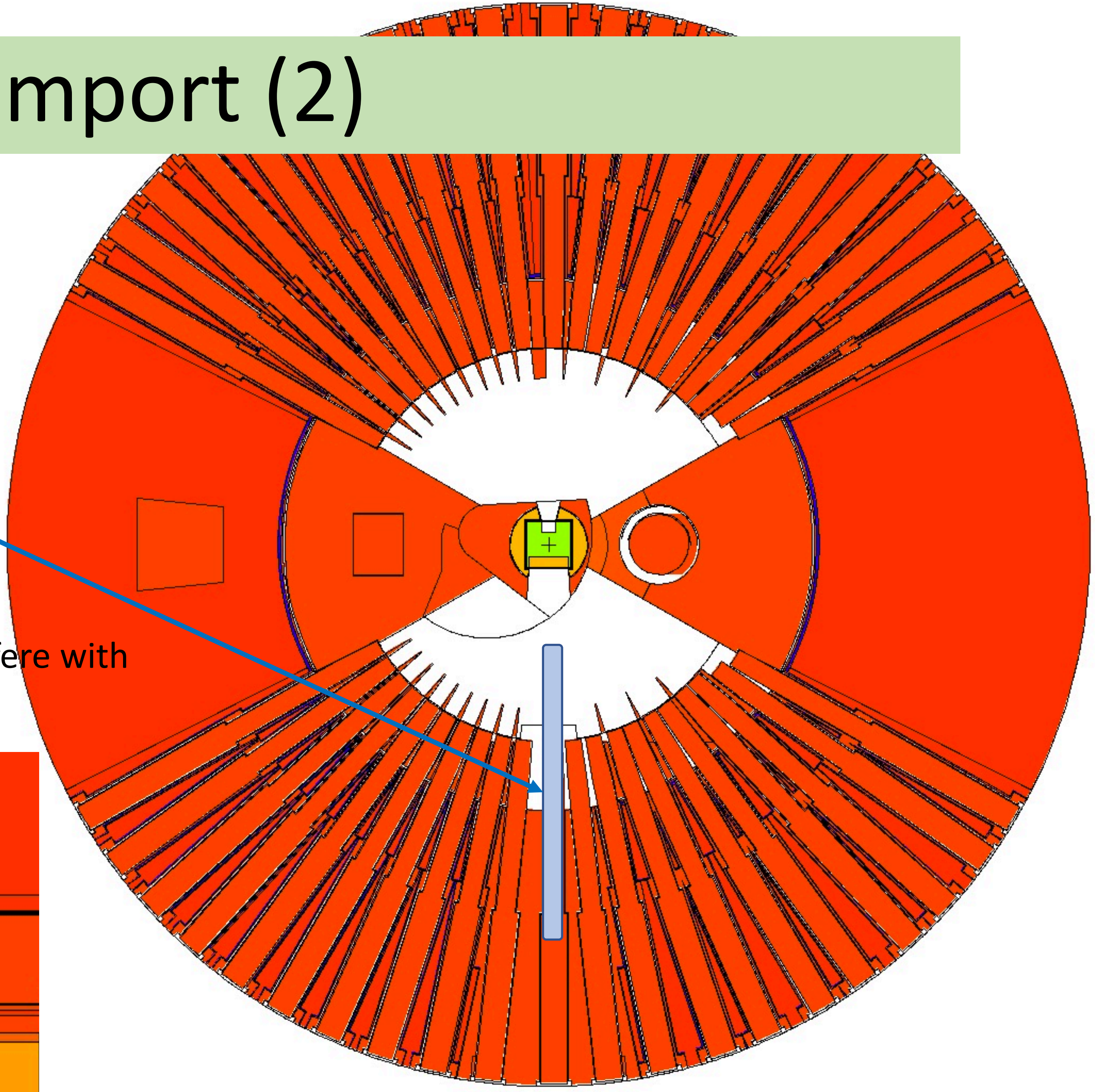
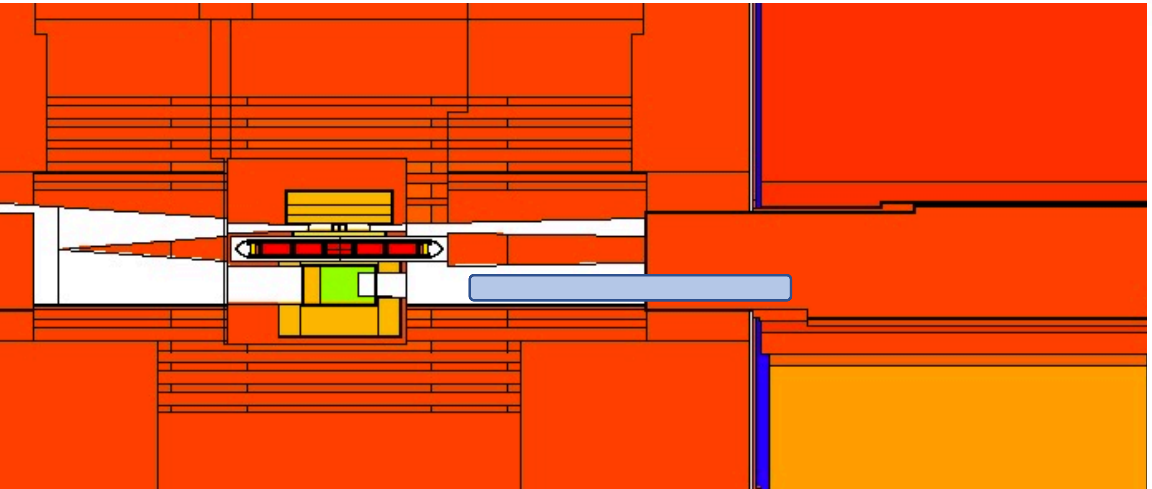
3. UCN source in beamport (2)

A variant is to push the UCN close to the center (see previous option)

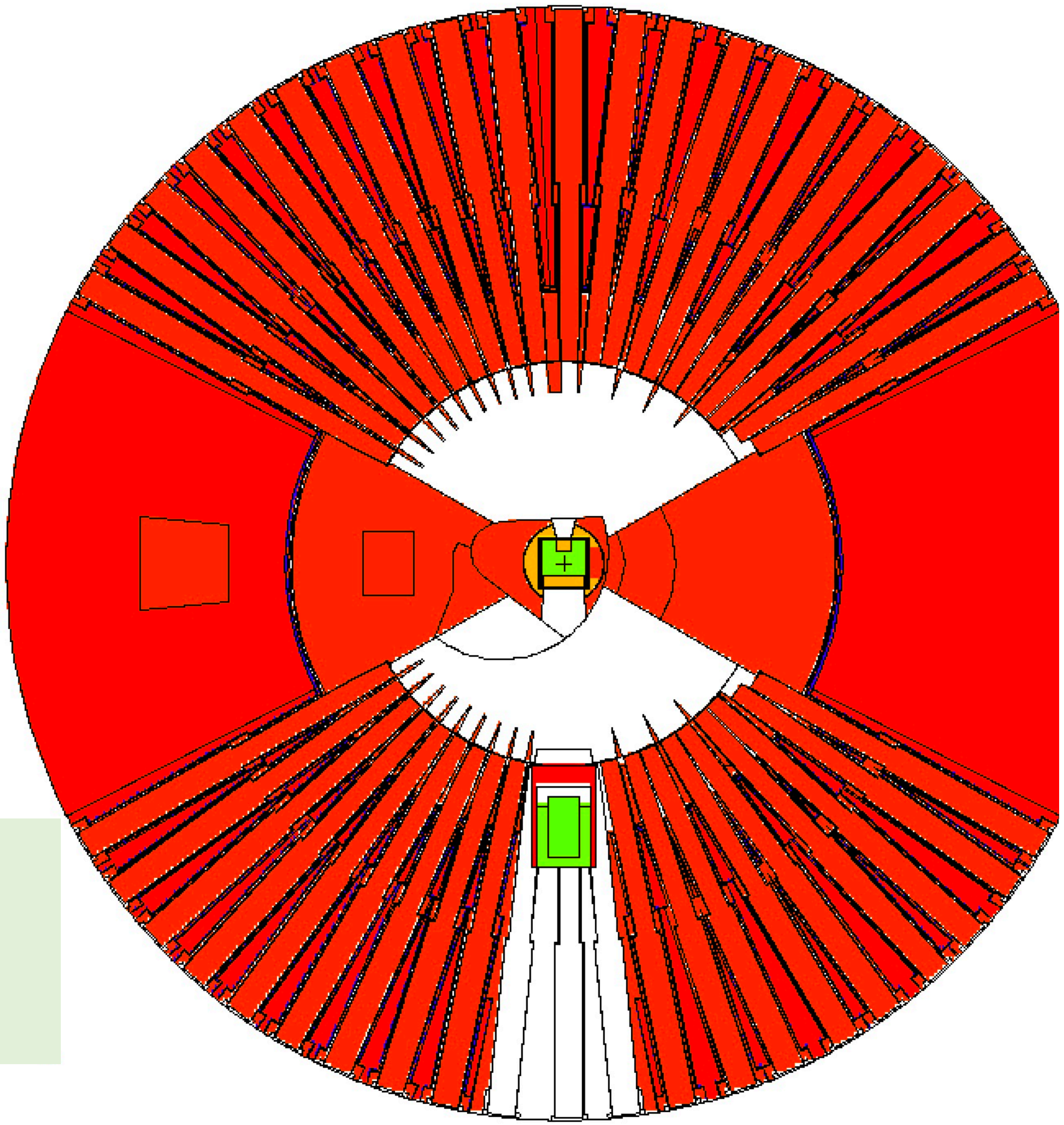
It would have to be manufactured in a way not to interfere with the upper moderator

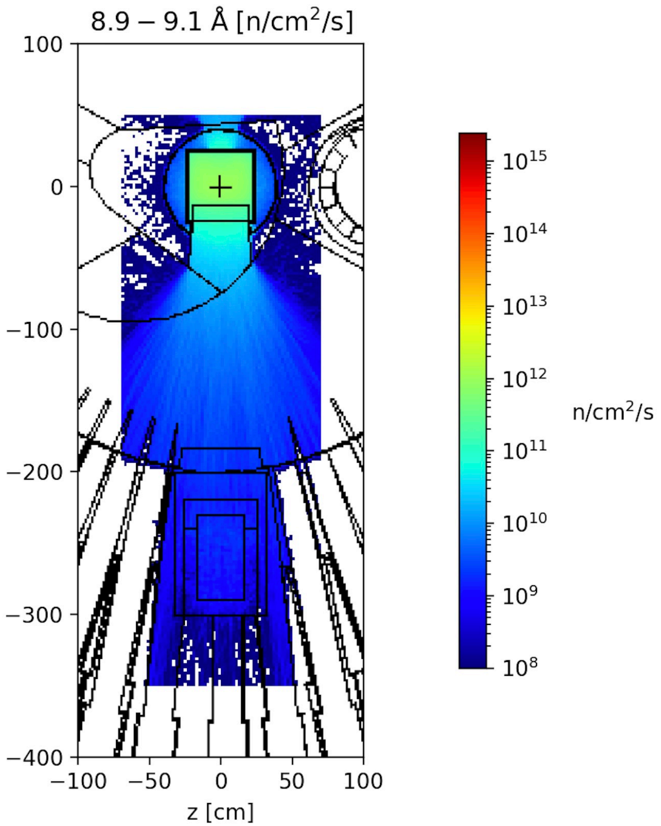




4. UCN source in large beamport

Alternatively, we could place a UCN source using the nnbar large beamport (equivalent to removing more than 3 beamports together, and without the constraints of not disturbing the upper moderator).





Calculated:
Heatload Helium (V=5.76e+04 cm^3):
Total: 8.36e+00 W,
Unit Volume: 1.45e-04 W/cm^3

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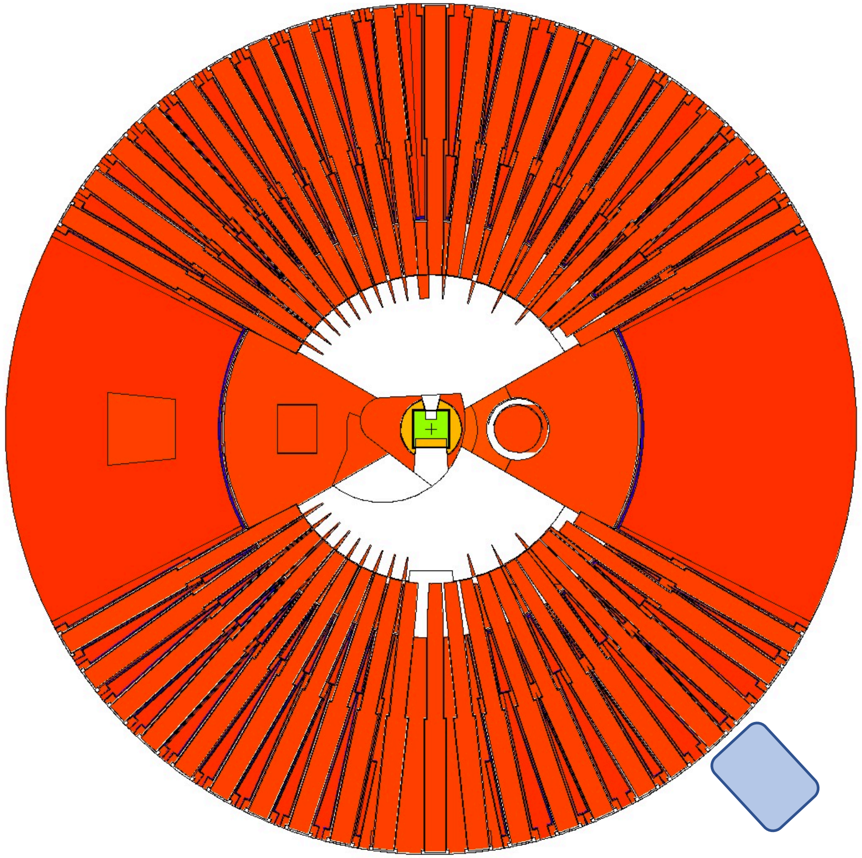
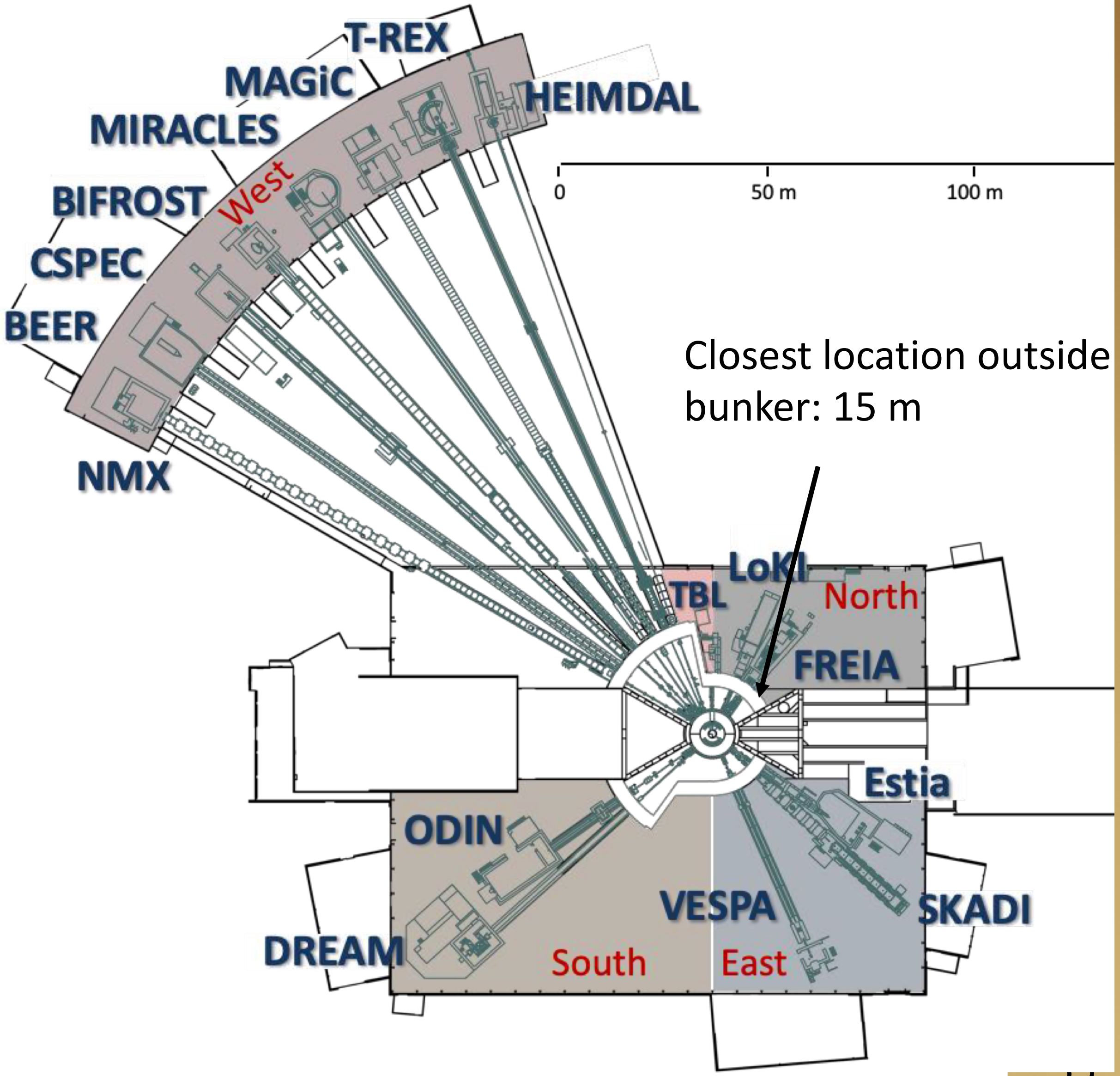
5. UCN in beam

Finally, we could have in beam option, placing the source outside the monolith

Closest location at 6 m (inside bunker)

Closest location outside bunker: 15 m





LENS WG3 Synergies in technological developments and Operation Subgroup on the moderator systems

HighNess

LENS LEAGUE OF ADVANCED EUROPEAN NEUTRON SOURCES

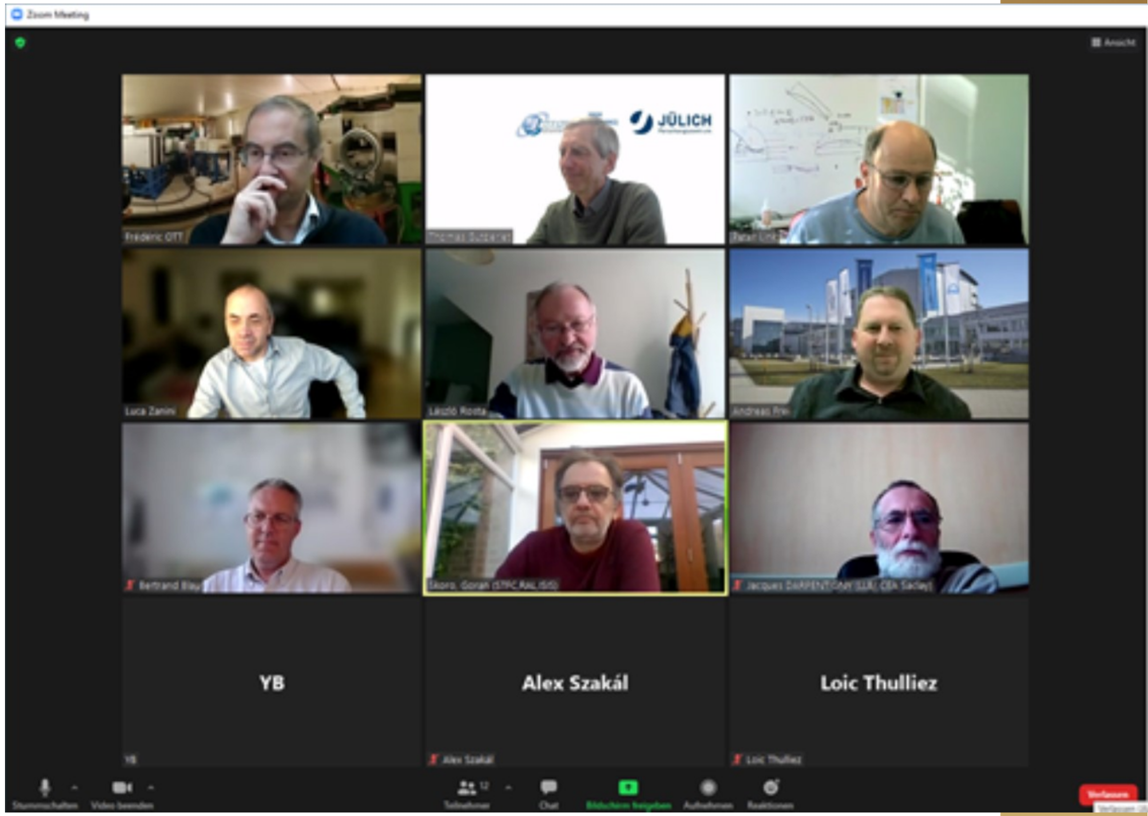
Identifying and discussing common areas of interest in moderators for collaborative work

First meeting held 21 October 2021

Examples of ongoing activities discussed

- UCN source at PSI (operating) and FRM-II (under construction)
- Development of moderators for compact sources Sonate and HBS.
- Work towards several upgrades at ISIS.
- Development of a moderator test facility at Budapest Research Center.

Next steps: Will organize (hopefully) physical meeting in Spring 2022 with the aim to start collaborations.



Visit https://lens-initiative.org/working-groups/

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CREMLIN PLUS

Connecting Russian and European Measures for Large-scale Research Infrastructures

HighNess

WP3 PIK: Collaboration with PIK

Objectives

The objective of this work package is to strengthen the scientific and technical cooperation between PIK and European neutron research infrastructures of mutual interest to European and Russian researchers.

WP3 will achieve its objective by undertaking research and activities in the following key areas:

- Joint development of advanced cold neutron sources
- Joint development of the instrumentation concept for reactor PIK
- Establish international bodies at PIK
- Development of the neutron user-based education platform and a user system
- Support strategic coordination of PIK on the whole

Task 3.1: High-brilliance cold neutron source (**FZJ**, NRC KI-PNPI, MTA EK)

Task 3.3: Development of advanced Very Cold Neutron Source (**ILL**, NRC KI-PNPI, JINR, PTI, UCA, UNIMIB, ESS)

visit https://www.cremlinplus.eu/work_programme/wp3_pik_collaboration_with_pik/

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THANK YOU FOR PARTICIPATING TO THIS WORKSHOP

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LENS LEAGUE OF ADVANCED EUROPEAN NEUTRON SOURCES

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APPENDIX: Important ESS parameters

Proton energy	2 GeV
power	2 MW (upgrade to 5 MW)
Pulse length	2.86 ms
Pulse frequency	14 Hz
Time between pulses	71 ms
Accelerator duty cycle	4 %
Ratio peak/time-average brightness	25

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